A QUANTIFIED APPROACH TO THE FUNCTIONAL LONGEVITY OF GEOSYNTHETIC ROLLED EROSION CONTROL PRODUCTS (GRECPS)

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ABSTRACT

Geosynthetic Rolled Erosion Control Products (GRECPs) have been utilized for decades in a multitude of applications to mitigate erosion resulting from land disturbance in civil construction projects. GRECPs vary from one type to another, ranging in performance and design life due to their composition and intended purpose. The coverage and durability of the GRECP are fundamental properties that can predict performance and fitness for use. Both coverage and durability will degrade over the design life of the GRECP to the point that fitness for use is unacceptable for the intended application. A standard approach is needed to quantify this material degradation over time. Through this analysis, the degradation of the GRECP's durability and coverage is predicted over time, field validated, and compared to their respective functional thresholds. The time at which the GRECP's durability or coverage reduces below the established functional thresholds is known as the GRECP's functional longevity.

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AF_{UV}, Ultraviolet Exposure Acceleration Factor

C_F, Functional Coverage

C_{ult}, Ultimate Coverage

C_{UVD}, Ultraviolet Reduced Coverage

$C_{UVD,BD}$, Ultraviolet and Biological Reduced Coverage

$C_{UVD,BD,CD}$, Ultraviolet, Biological, and Chemical Reduced Coverage

$C_{UVD,BD,CD,MC}$, Ultraviolet, Biological, Chemical, and Material Construction Reduced Coverage

$C_{UVD,BD,CD,MC,MQT}$, Ultraviolet, Biological, Chemical, Material Construction, and Material Quality Reduced Coverage

DF_{BDC}, Biological Deceleration Factor

DF_{UV}, Ultraviolet Deceleration Factor

RF_{BDC}, Coverage Biological Reduction Factor

RF_{BDT}, Tensile Strength Biological Reduction Factor

RF_{CD}, Chemical Reduction Factor

RF_{MC}, Material Construction Reduction Factor

RF_{MQC}, Coverage Material Quality Reduction Factor

RF_{MQT}, Tensile Strength Material Quality Reduction Factor

RF_{UVDC}, Coverage Ultraviolet Reduction Factor

RF_{UVDT}, Tensile Strength Ultraviolet Reduction Factor

t_{AC}, Accelerated Ultraviolet Exposure Duration

T_F, Functional Tensile Strength

T_{ult}, Ultimate Tensile Strength

t_{UV}, Ultraviolet Exposure Duration

T_{UVD}, Ultraviolet Reduced Tensile Strength

$T_{UVD,BD}$, Ultraviolet and Biological Reduced Tensile Strength

$T_{UVD,BD,CD}$, Ultraviolet, Biological, and Chemical Reduced Tensile Strength

$T_{UVD,BD,CD,MC}$, Ultraviolet, Biological, Chemical, and Material Construction Reduced Tensile Strength

$T_{UVD,BD,CD,MC,MQT}$, Ultraviolet, Biological, Chemical, Material Construction, and Material Quality Reduced Tensile Strength

CHAPTER I

INTRODUCTION

Geosynthetic Rolled Erosion Control Products (GRECPs) have been utilized for decades in a multitude of applications, including stormwater channels, slopes, levees, canals, and stream banks, among others, to mitigate erosion resulting from land disturbance in civil construction projects. GRECPs vary from one type to another, providing a range in performance and design life due to their composition and intended purpose. The coverage and durability of the GRECP are fundamental properties that can predict performance and fitness for use in an application.

GRECPs encompass the geosynthetic product categories of (1) Turf Reinforcement Mats (TRMs) and (2) High Performance Turf Reinforcement Mats (HPTRMs). While the majority of TRMs are composed of fully synthetic materials such as polypropylene, polyethylene, polyester, or nylon, some TRMs are composed of both synthetic and organic materials. TRMs are manufactured using various techniques, classified as stitch-bonded, woven, and/or heat-bonded. HPTRMs are stitch-bonded, woven, and/or heat-bonded as well but must be composed of fully synthetic materials with no organic materials and have a minimum tensile strength of 3,000 lb/ft per American Society of Testing and Materials (ASTM) D-6818. TRMs and HPTRMs act to provide protection to the soil and seed below in the unvegetated to partially vegetated states as well as providing vegetation reinforcement in the partially vegetated to fully vegetated states.

Coverage of a GRECP is defined as the ability of the product to retain soil and reinforce the stems and roots of vegetation in turf reinforcement applications. Durability of a GRECP defines the ability of the product to maintain coverage upon exposure to environmental stresses. Both durability and coverage will decline over the design life of the GRECP to the point that fitness for use is unacceptable for the intended application. The quantified duration of this decline is the “functional longevity” of the GRECP; an essential predictor of long-term performance. Explained herein are several concepts or properties that must be considered in order to capture this "functional longevity". These concepts or properties include, but are not limited to tensile strength and light penetration as they vary with the materials UV degradation, biological degradation, chemical degradation, material construction, and material quality. Due to the various manufacturing techniques and material compositions, a process or method should now be developed to quantify their "functional longevity" in years in order to accurately compare them.

CHAPTER II

LITERATURE REVIEW

The performance of a GRECP is dependent upon many variables, with some of the most important being coverage and durability. The coverage of a GRECP dictates how well the material retains soil and reinforces vegetation while the durability of the GRECP seeks to maintain that coverage when environmental stresses are present. As the coverage and durability of the GRECP reduces over the design life of the project, there is a point in time where the material will cease to function. The amount of time it takes to get to this point is known as the material's "functional longevity". The functional longevity of a given GRECPs can be determined by evaluating it's coverage, displayed through light penetration, and durability, displayed through tensile strength, as a function of UV degradation, biological degradation, chemical degradation, material construction, and material quality.

Tensile Strength

The tensile strength of a GRECP, as tested by American Society of Testing and Materials (ASTM) D-6818 does not directly affect the material's hydraulic performance. A higher tensile strength GRECP does not necessarily lend to increased erosion protection, or greater hydraulic performance. While the performance of GRECPs has traditionally been focused on hydraulic parameters Miller, Fischenich, & Thornton found that actual performance is also dependent upon certain non-hydraulic factors. When designing for the use of a GRECP, an engineer must select material that can withstand the full range of conditions expected during the project's design life. Some non-hydraulic factors that can induce stress on the GRECP include slope instability, mechanical connections to hard structures, debris loading, maintenance or recreational traffic, or installation loading (Miller, Fischenich, & Thornton, 2012).

Khanna, S. (2005) from Texas A&M University sought to further understand how GRECPs perform throughout their lifespan. In order to gather realistic information seven GRECPs of various types were installed in the field. After a period of three (3) years test specimens were removed, tested for tensile strength, stiffness, and light penetration, and compared to unused specimens. While there was no firm conclusion from the stiffness and light penetration, it was reported that the tensile strength of stitch-bonded fully synthetic and stitch-bonded composite materials reduced by 50% while the natural materials reduced by 80% over the three (3) year period (Khanna, 2005).

Propex (2012) reported that the tensile strength of a GRECP is the single most important predictor of its long-term performance. GRECPs are often utilized in areas subject to erosive forces of wind and water as well as non-hydraulic stresses. As construction and maintenance loadings, frequent maintenance (mowing), transported debris, and burrowing animals have the potential to damage the GRECP, it must resist these non-hydraulic stresses upon installation and throughout the project's design life. GRECPs with the highest tensile strength are best-suited for the most critical of these applications, and retention of strength over a predicted lifespan is imperative to assuring that the GRECP will perform as a permanent application solution (Durham, 2012).

The tensile strength of a GRECP is not constant but is affected over the life of the material by deterioration due to UV exposure and chemical degradation. The tensile strength of a fully synthetic polypropylene GRECP, for example, being essentially chemically inert will not be effected by biological or chemical degradation but will be severely reduced by UV exposure if not properly stabilized. The consistency of a GRECP's tensile strength is also dependent upon the material construction and material quality.

Light Penetration

The light penetration (inverse of percent coverage) of a GRECP, as tested by ASTM D-6567 is one of the single most important index properties contributing to hydraulic performance. While ASTM D-6567 is in need of improvement to better compare products, light penetration points toward the percent open area or percent coverage of the GRECP. Research has shown that GRECPs with lower light penetration and greater percent coverage can achieve a higher level of hydraulic performance than those with higher light penetration and less percent coverage (Hughes & Thornton, 2014). A GRECP with lower light penetration and greater percent coverage will protect and retain more soil when vegetation is not fully established and will entangle and reinforce the fully established vegetation to a greater degree as compared to a GRECP with a higher light penetration and less percent coverage.

The Light Penetration of a GRECP has long been considered a “quality control” test method with little or no bearing on the performance. In simplistic terms, a GRECP with a lower percentage value of light penetration is visually identified as a “denser” product, possessing a composition that includes more inlaid material, a tighter woven construction. As the light penetration value increases, one can expect the material to have significantly less density across the face of the mat. Subsequently, the light penetration value of a GRECP has been used interchangeably with a description of its “open area” (Durham, 2014). However, research at Colorado State University has shown that GRECPs having lower values for light penetration are able to provide superior hydraulic performance through its design life. This performance improvement is most notable during the vegetation's early root establishment period. This improved performance is attributed to the low light penetration allowing for increased retention of soil under the GRECP, keeping the newly established sod roots from dislodging from the underlying soil, and limiting the fine aggregate particles within the soil from migrating up through the GRECP (Durham, 2014).

Hughes & Thornton of Colorado State University (CSU) completed several wave overtopping simulations on bare soil, unreinforced vegetation, and vegetation reinforced with varying GRECPs. Through each test the root length, root surface area, average root diameter, and root volume of the vegetation was measured when possible. These test results were then analyzed along with additional test results from the United States Army Corps of Engineers (USACE). It was found that there was an obvious improvement in performance with the inclusion of a GRECP (Hughes & Thornton, 2014).

Hughes & Thornton hypothesized that performance of the vegetated GRECPs was a function of the materials light penetration, showing that a material with a lower light penetration will help retain more soil. Furthermore, it should be expected that a GRECP with 30% light penetration should not be able to withstand as much hydraulic stresses as a GRECP with 15% light penetration. Hughes & Thornton determined that the performance of the vegetated GRECP is a function of the material's light penetration, the underlying soil type, and the robustness of the vegetation's root system that had penetrated the mat and the underlying soil (Hughes & Thornton, 2014).

Light penetration, like tensile strength is not constant but is affected over the life of the material by deterioration due to UV exposure, biological degradation, and chemical degradation. The light penetration of a fully synthetic polypropylene GRECP, for example, being essentially chemically inert will not be effected by biological or chemical degradation but will be severely increased by UV exposure if not properly addressed. The light penetration of GRECPs that consist of both synthetic and organic materials could be subjected to a combination of UV exposure, biological degradation, and chemical degradation, depending on the composition of the covering component of the GRECP.

Ultraviolet Degradation

All GRECPs contain some percentage of synthetic material. This synthetic material can be some form of polypropylene, polyethylene, polyester, or nylon. Whether these materials contain recycled content or all virgin material, they are all susceptible to UV degradation in varying degrees. In order to counteract this degradation, the manufacturers of these materials can incorporate additives in the beginning of the manufacturing process. These additives protect the material and degrade in its place. Once the additive has been fully consumed, the protected polymer will then begin to degrade. As the UV degradation occurs, the material's strength and coverage reduces. If the GRECP in question relies on the synthetic material for strength, then the GRECPs tensile strength will be reduced over time with UV exposure. If the GRECP in question relies on the synthetic material for coverage, then the GRECPs coverage will be reduced over time with UV exposure (TenCate, 2010).

Propex (2014) reported that Sunlight can be divided into three categories by wavelength, where infrared and visible light have wavelengths above 400 nm and UV light has wavelengths less than 400 nm. As geotextiles are exposed, photo-initiated degradation occurs when the energy from the UV light begins to break the bonds within the polymer structure. In order to protect against this degradation, geotextile manufactures add stabilizers to their geotextile fibers and yarns. The UV degradation begins on the surface of the polymer and works through to the core. Thus, fibers or yarns of larger diameter will generally degrade more slowly. Woven geotextiles tend to utilize larger diameter yarns and in turn will also degrade more slowly. ASTM D-4355 is standardly used for determining the UV stability of a geotextile, exposing the material to a xenon-arc light source under controlled conditions of temperature and humidity. The xenon-arc light source closely mimics that of natural sunlight in the UV range. The test uses a combination of high light intensity and elevated temperature to degrade the specimens more rapidly than would be experienced in a natural environment in the same amount of time. After exposure, the specimen's tensile strength is tested and compared to the original strength, shown as a percent of strength retained. While the test results from ASTM D-4355 should not be directly utilized, they can be correlated to outdoor exposure (Propex, 2014)

Propex (2006) reported that while polypropylene is essentially chemically inert, it is commonly degraded by an oxidation reaction induced by UV radiation. To combat the oxidation process antioxidants, such as hindered amine light stabilizers (HALS) or carbon black are added to the polymer during the manufacturing of the geosynthetic. As the antioxidants are consumed, the resistance of the polymer to oxidation will decrease. The rate of polymer oxidation is dependent upon how much and what type of antioxidant is utilized and how well it is distributed throughout the polymer (Propex, 2006).

TenCate (2010) reported that UV exposure can damage geosynthetics and reduce their ability to function. This damage can be seen in changes in both the material's physical appearance and performance, and is most easily seen in reduction in strength and density over time. One test to assist in quantifying this strength reduction is ASTM D-4355, which uses a xenon arc light source to provide UV exposure while cycling through heat and moisture variations. While UV exposure is not consistent across the world, the amount of radiation across the world is known. This exposure can then be compared to the amount of exposure from the specific test and a correlation can be made. It should also be noted that there are other environmental factors that can affect the deterioration of the geosynthetic material (TenCate, 2010).

GEOfabrics (2011) reported that geotextiles and other geosynthetics are used in various applications, demanding extreme durability throughout their design life. There are many factors that can affect the durability of a geosynthetic material, such as physical structure, type of polymer used, and quality of material and the manufacturing process. One important factor to consider is the geosynthetics resistance to weathering, where the mechanism of degradation is the absorption of UV light by the polymer. The energy from the UV light begins to break down the polymer, creating a chain reaction that continues to weaken the polymer. Geosynthetics that are utilized in exposed conditions therefore must be protected with appropriate additives to minimize the detrimental effects of exposure to UV light (GEOfabrics, 2011).

When non-hydraulic stresses are applied to the GRECP, one must consider if the material has adequate tensile strength to resist tearing and enough UV stability to maintain that required tensile strength. Projects that fail to consider UV stability and tensile strength will have a higher probability of failure. UV exposure when combined with highly variable temperature and moisture causes the greatest measurable degradation in polymers commonly used to manufacture GRECPs. The UV exposure of each site should be evaluated in order to ensure the long term performance of the GRECPs. Even if full vegetation coverage is expected, some amount of UV exposure will be seen during construction, following flood events, and prior to or in case of lack of vegetation (Miller, Fischenich, & Thornton, 2012).

Although installed GRECPs are typically covered with a combination of soil and vegetation, one must assume that full exposure to constant sunlight is the critical design condition. In arid locations (such as the Southwestern United States), GRECPs are often installed with no soil fill or vegetation and are subject to intense radiation for a vast majority of the year. In order to perform in these arid environments, various stabilizers are added to the polymer so as to protect against photo-oxidation. Assurance of the effectiveness of the UV stabilizers consists of both accelerated laboratory testing per ASTM D-4355 as well as documented field performance (Durham, 2012).

The most direct way to test a GRECP's UV stability would be to place it exposed in a chosen location and after a determined amount of time, such as 50 years, exhume the GRECP, and test it for retained tensile strength. However, manufacturers as well as users of these materials do not have the luxury of waiting even 5 years, let alone 50 years for testing. In order to obtain some information, the material is tested using ASTM D-4355. This test simulates accelerated UV exposure with temperature and moisture changes for up to and over 10,000 hours (about 1 year and 52 days). After the exposure the materials strength is tested per ASTM D-6818 and reported as a percentage retained after exposure (Propex, 2014).

The data from the accelerated testing must then be correlated to field performance. Historically, very few correlations from field performance have been utilized. Instead a general correlation developed from research on polypropylene geomembranes has been used for all materials. The Geosynthetic Research Institute (GRI) (2011) performed several studies in order to help predict the lifetime of geomembranes in both exposed and unexposed conditions. In this research a polypropylene geomembrane was exhumed after being fully exposed to UV radiation for 26 months in Arizona and tested for retained tensile strength. The retained tensile strength of 50% was compared to the accelerated testing and it was found that the testing duration corresponding to 50% strength retained was 6.1 months. Comparing the field duration (26 months) to the testing duration (6.1 months) yielded an acceleration factor of 4.3 (Koerner, Hsuan, & Koerner, 2011). This correlation is specific to Arizona and to other areas with similar daily UV radiation. If an acceleration factor is needed for another region then the daily UV radiation of the two regions can be compared in order to appropriately scale the acceleration factor.

Biological Degradation

When selecting a GRECP, one must consider the material types being utilized. Propex (2006) reported that while polypropylene is not a food source for and cannot be digested by insects and animals, they will not be adversely affected by ingesting small quantities of polypropylene (Propex, 2006). If a GRECP is not entirely synthetic then it will contain some portion of organic material, such as straw or coconut. GRECPs that contain organic components will perform very differently before and after the temporary components are gone (Miller, Fischenich, & Thornton, 2012). While organic material does not have the tendency to degrade from UV exposure it is susceptible to biological degradation. The majority of GRECPs containing organic material rely on the organic material for coverage. In this case the GRECPs coverage will be reduced over time due to biological degradation.

Chemical Degradation

Any GRECP containing synthetic material is susceptible to chemical degradation. Apart from extreme environmental conditions, chemical degradation can be most readily seen through hydrolysis of polyester or nylon. Polyester can be significantly affected by moisture and can be degraded over a wide range of pH levels. Nylon can be significantly affected by the presence of moisture because it absorbs moisture and loses strength rapidly as humidity and temperature increase. If the GRECP in question relies on the synthetic material for strength, than the GRECPs tensile strength will be reduced over time. If the GRECP in question relies on the synthetic material for coverage, then the GRECPs coverage will be reduced over time.

EuroGeo4 Keynote paper (2014) reported that when attempting to determine the long-term performance of geosynthetics, both chemical and mechanical degradation can occur. Chemical degradation can occur through the oxidation of polypropylene or the hydrolysis of polyester. While this research focuses on the oxidation of polypropylene by UV exposure, it sheds light on the potential hydrolysis of polyester materials. The hydrolysis of polyester is greatly affected by the chemical and physical structure of the product. Tests were run on three polyester geosynthetics in different pH environments and results indicated that the strength of these materials can be reduced by 50% after anywhere from 2 to 161 years of exposure. Research has further established a service life of 25 years for polyester geosynthetics not exposed to other forms of degradation. For service longer than 25 years, products should be evaluated further (Hsuan, et al., 2014).

Propex (2006) reported that polypropylene is a very durable and versatile polymer that is commonly utilized in the manufacture of geosynthetics. Unlike polyester, polypropylene does not absorb water nor does the presence of water adversely affect its strength. Polypropylene is also shown to be very resistant to certain concentrations of aggressive chemicals; does not support, attract, or deteriorate from fungal growth; and can withstand temperatures ranging from -40 to 320 degrees Fahrenheit (Propex, 2006).

Material Construction

There are several different material construction types of GRECPs, such as stitch-bonded, heat-bonded, and woven. While the material construction does not directly relate to the tensile strength or light penetration of a GRECP it can greatly affect its durability and even reduce its functional longevity. While composite materials, such as stitch-bonded and heat-bonded GRECPs may have tensile strength in the Machine Direction (MD) or the Cross-Machine Direction (CD) they could very easily be pulled apart if the stitching or lamination fails. This material failure would result in the loss of coverage and loss in overall performance. Woven GRECPs however are homogeneous in construction, providing strength in all directions without pulling apart and in turn maintaining coverage.

GRECPs that are composed of multiple components stitched or laminated together may also have varying performance over time as unraveling of stitching or delamination could occur, resulting in potentially catastrophic failures. A composite GRECP also may not be able to withstand cutting, tearing, or other breaks in the fabric as might be required to work around trees or other vegetation or to drive in percussion driven earth anchors. In contrast, a woven material can be cut to accommodate vegetation even in severe slope settings that require materials with significant tensile strength, without compromising the installation (Miller, Fischenich, & Thornton, 2012).

Material Quality

The manufacturing of GRECPs inherently contains variation depending on the specific manufacturing process. Additionally, various test methods are utilized to quantify the index and performance properties of the GRECP. All test methods used to quantify material properties further contribute to the variability. To properly account for this variation and accurately represent the material characteristics, manufacturers of GRECPs publish properties as either Minimum Average Roll Values (MARVs) or Typical values as defined in ASTM D-4439. The importance of these values is in their statistical significance. A Typical value is defined as the average or arithmetic mean of all historic test data points, showing a 50% degree of confidence. A MARV is determined by subtracting two times the standard deviation from the Typical value for normally distributed data, showing a 97.7% degree of confidence. The ability to utilize MARV or Typical values is dependent upon the frequency of testing. MARV should be required where possible in order to have consistent quality in tensile strength and coverage. The use of Typical values indicates a lack of consistency and quality (Propex, 2014).

CHAPTER III

PROBLEM STATEMENT

For every possible GRECP application there is a specific need for a level of durability and coverage to provide adequate performance. These application specific requirements are the thresholds that a product needs to achieve in order to function, or functional thresholds. Because the durability and coverage of GRECPs are not constant, but degrade over time due to environmental conditions, GRECPs will not always meet the required functional thresholds. The point in time where the materials anticipated tensile strength or coverage reduces below their respective functional threshold is established as their functional longevity for that set of environmental conditions

Because GRECPs are composed of such varying materials, manufactured with different processes, and held to different quality standards, an approach is needed to consistently quantify the material degradation over time for specific GRECPs so that, when compared to a standard functional threshold, the GRECPs functional longevity can be determined. In order to determine the GRECPs functional longevity, the modes by which the GRECP's tensile strength and coverage will degrade over time will be evaluated. Based on the determined modes of degradation, decreases in tensile strength and coverage over time can then be applied. The changes in tensile strength and coverage over time for each GRECP can be plotted and compared to a functional threshold for tensile strength and coverage. The time in years at which the GRECP's tensile strength or coverage reduces below the functional threshold will be known as the GRECP's functional longevity.

CHAPTER IV

METHODOLOGY

With the theories around the proposed problem statement established, a process can now be implemented in order to consistently quantify the functional longevity of several GRECPs that are currently available within the North American marketplace.

Assemble Information

The first step in the process is to gather publically available information from published product data sheets. While the information available in a product data sheet is not direct data, it is published with inherent conservatism and is able to capture the potential variability of the manufacturing and testing processes. Each individual product data sheet is reviewed in order to record the GRECP's general category, material construction type, and the material associated with tensile strength and coverage. GRECP material properties such as tensile strength per ASTM D-6818, light penetration per ASTM D-6567, and UV resistance per ASTM D-4355 are also recorded along with the statistical significance of the data.

Evaluate Modes of Degradation

Once the data is compiled, the individual products must then be evaluated in order to determine the modes by which the product's tensile strength and coverage will degrade over time. GRECPs containing synthetic material are susceptible to UV and chemical degradation while GRECPs containing organic material are susceptible to biological degradation. The reduction factors for confidence due to material construction are determined based on material construction type and reduction factors for confidence due to material quality are determined based on the statistical significance of the GRECP's published values.

Apply Effects of Degradation

Based on the determined modes of degradation, reductions in tensile strength and coverage over time can then be applied. UV degradation is applied to GRECPs that utilize synthetic materials for tensile strength and/or coverage. The GRECP's original tensile strength is reduced based on the published strength retention from UV degradation per ASTM D-4355 at each respective exposure duration. For GRECPs utilizing synthetic materials to achieve coverage, the GRECP's original coverage is also reduced based on the published UV degradation at each respective exposure duration. The exposure duration published per ASTM D-4355 is utilized and accelerated by an assumed factor of 4.3 to establish the time at the respective tensile strength and coverage values. Biological degradation is then applied to GRECPs that utilize organic materials for coverage. Biological degradation is not applied to tensile strength because there are not any GRECPs that utilize organic material for tensile strength. The original coverage of the GRECPs containing organic material is reduced based on the industry accepted design life of straw, a straw and coconut fiber blend, and coconut fiber. While it is understood that chemical degradation of polyester and nylon GRECPs can occur, additional testing that is outside of the scope of this research is needed in order to provide further quantification.

In order to account for the confidence in the material construction of stitch-bonded and heat-bonded GRECPs a reduction factor of 0.9 is applied to the GRECP's tensile strength and coverage. This reduction factor translates through to the GRECP's reduced tensile strength and coverage. In order to account for the confidence in the material quality of all GRECPs an additional reduction factor is applied to the GRECP's original tensile strength and coverage. This reduction factor is dependent upon the statistical significance of the published values in question where a MARV receives a reduction factor of 0.977 and a Typical value receives a reduction factor of 0.5.

Evaluate Results

With the reductions in tensile strength and coverage for each product established, these values can then be plotted versus the accelerated exposure time. An exponential curve can be fitted to each set of data and extrapolated, comparing the anticipated tensile strength and coverage to their respective functional threshold. The point in time where the materials anticipated tensile strength or coverage reduces below their respective functional threshold is established as their functional longevity for that set of environmental conditions.

CHAPTER V

DATA ANALYSIS AND RESULTS

Assemble Information

Data specific to each individual GRECP is compiled by gathering product data sheets from each manufacturer's website. Each product data sheet can be seen in APPENDIX A. While the information available in a product data sheet is not direct data, it is published with inherent conservatism and is able to capture the potential variability of the manufacturing and testing processes. Each individual product data sheet is reviewed and the following information is recorded:

- General information such as the GRECP category, the material construction type, the material associated with tensile strength, and the material associated with coverage
- Material strength information such as tensile strength in Machine Direction (MD) and Cross-Machine Direction (CD) of the GRECP per ASTM D-6818 presenting strength in both the "x" and "y" direction and statistical significance of the tensile strength data
- Material coverage information such as the light penetration of the GRECP per ASTM D-6567 and the statistical significance of the light penetration data
- UV resistance information on the GRECP per ASTM D-4355 for exposures of 500, 1,000, 2,000, 3,000, 6,000, and 10,000 hours

The product information is compiled and shown in Table 1 through Table 4.

Table 1 GRECP General Information

Manufacturer / Distributor	Product Name	GRECP Category	Material Associated with Tensile Strength	Material Associated with Coverage	Material Construction
American Excelsior	Recyclex TRM	TRM	Polypropylene	Recycled Polyester	Stitch-Bonded
East Coast Erosion Control	ECC-3	TRM	Polypropylene	Coconut	Stitch-Bonded
	ECP-2	TRM	Polypropylene	Polypropylene	Stitch-Bonded
	ECSC-3	TRM	Polypropylene	Straw / Coconut	Stitch-Bonded
	T-RECS	HPTRM	Polypropylene	Polypropylene	Woven
North American Green	C350	TRM	Polypropylene	Coconut	Stitch-Bonded
	SC250	TRM	Polypropylene	Straw / Coconut	Stitch-Bonded
	W3000	HPTRM	Polypropylene	Polypropylene	Woven
Profile	Enkamat 7020	TRM	Nylon	Nylon	Heat-Bonded
	Enkamat R45	HPTRM	Nylon	Nylon	Heat-Bonded
Propex	Landlok 300	TRM	Polypropylene	Polypropylene	Woven
	Landlok 450	TRM	Polypropylene	Polypropylene	Stitch-Bonded
	Pyramat	HPTRM	Polypropylene	Polypropylene	Woven
Western Excelsior	Excel PP5-10	TRM	Polypropylene	Polypropylene	Stitch-Bonded
	PP5-Heavy Duty	TRM	Polypropylene	Polypropylene	Woven
	PP5-Xtreme	HPTRM	Polypropylene	Polypropylene	Woven

Table 2 GRECP Material Strength

Manufacturer / Distributor	Product Name	Ultimate Tensile Strength, MD (lb/ft)	Ultimate Tensile Strength, CD (lb/ft)	Statistical Significance
American Excelsior	Recyclex TRM	387.6	340.8	Typical
East Coast Erosion Control	ECC-3	802.0	790.0	Typical
	ECP-2	400.0	400.0	Typical
	ECSC-3	756.0	632.0	Typical
	T-RECS	3,000.0	3,000.0	MARV
North American Green	C350	625.0	768.0	Typical
	SC250	620.0	737.0	Typical
	W3000	3,600.0	3,800.0	Typical
Profile	Enkamat 7020	175.0	175.0	MARV
	Enkamat R45	3,000.0	3,000.0	MARV
Propex	Landlok 300	2,000.0	1,800.0	MARV
	Landlok 450	400.0	300.0	Typical
	Pyramat	4,000.0	3,000.0	MARV
Western Excelsior	Excel PP5-10	249.6	212.4	Typical
	PP5-Heavy Duty	2,500.0	2,250.0	MARV
	PP5-Xtreme	4,000.0	3,000.0	MARV

Table 3 GRECP Material Coverage

Manufacturer / Distributor	Product Name	Light Penetration (% Passing)	Statistical Significance
American Excelsior	Recyclex TRM	55	Typical
East Coast Erosion Control	ECC-3	14	Typical
	ECP-2	18	Typical
	ECSC-3	7	Typical
	T-RECS	34	Typical
North American Green	C350	9	Typical
	SC250	9	Typical
	W3000	12	Typical
Profile	Enkamat 7020	95	Typical
	Enkamat R45	95	Typical
Propex	Landlok 300	35	MARV
	Landlok 450	20	Typical
	Pyramat	10	MARV
Western Excelsior	Excel PP5-10	25	Typical
	PP5-Heavy Duty	30	Typical
	PP5-Xtreme	30	Typical

Table 4 GRECP UV Resistance

Manufacturer / Distributor	Product Name	UV Resistance (% Retained), DF_{UV}					
		At 500 hours	At 1,000 hours	At 2,000 hours	At 3,000 hours	At 6,000 hours	At 10,000 hours
American Excelsior	Recyclex TRM	-	90	-	-	-	-
East Coast Erosion Control	ECC-3	-	98	-	-	-	-
	ECP-2	-	82	-	-	-	-
	ECSC-3	80	-	-	-	-	-
	T-RECS	-	-	-	-	91	-
North American Green	C350	-	86	-	-	-	-
	SC250	-	100	-	-	-	-
	W3000	-	-	-	80	-	-
Profile	Enkamat 7020	-	80	-	-	-	-
	Enkamat R45	-	-	80	-	-	-
Propex	Landlok 300	-	-	-	90	-	-
	Landlok 450	-	80	-	-	-	-
	Pyramat	-	-	-	-	90	85
Western Excelsior	Excel PP5-10	100	90	-	-	-	-
	PP5-Heavy Duty	100	-	-	90	-	-
	PP5-Xtreme	100	-	-	-	90	-

Evaluate Modes of Degradation

With the individual product information as shown in Table 1 through Table 4, the understanding of material degradation is then utilized to develop the modes of degradations for the varying components of each product. The modes of degradation are determined for the products in question and shown in Table 5.

Table 5 GRECP Modes of Degradation

Manufacturer / Distributor	Product Name	Tensile Strength Modes of Degradation	Coverage Modes of Degradation
American Excelsior	Recyclex TRM	UVD[1], CD[2], MC[3], MQ[4]	UVD, CD, MC, MQ
East Coast Erosion Control	ECC-3	UVD, MC, MQ	UVD, BD[5], MC, MQ
	ECP-2	UVD, MC, MQ	UVD, MC, MQ
	ECSC-3	UVD, MC, MQ	UVD, BD, MC, MQ
	T-RECS	UVD, MQ	UVD, MQ
North American Green	C350	UVD, MC, MQ	UVD, BD, MC, MQ
	SC250	UVD, MC, MQ	UVD, BD, MC, MQ
	W3000	UVD, MQ	UVD, MQ
Profile	Enkamat 7020	UVD, CD, MC, MQ	UVD, CD, MC, MQ
	Enkamat R45	UVD, CD, MC, MQ	UVD, CD, MC, MQ
Propex	Landlok 300	UVD, MQ	UVD, MQ
	Landlok 450	UVD, MC, MQ	UVD, MC, MQ
	Pyramat	UVD, MQ	UVD, MQ
Western Excelsior	Excel PP5-10	UVD, MC, MQ	UVD, MC, MQ
	PP5-Heavy Duty	UVD, MQ	UVD, MQ
	PP5-Xtreme	UVD, MQ	UVD, MQ

1 – Ultraviolet Degradation
2 – Chemical Degradation
3 – Material Construction
4 – Material Quality
5 – Biological Degradation

Apply Effects of Degradation

Each product now has an established set of physical components, all contributing in some way to the material's tensile strength and coverage. The composition, construction, and consistency of these physical components affect the modes of degradation related to tensile strength and coverage. The effects of degradation are now to be applied to each product's tensile strength and coverage where applicable.

Ultraviolet Degradation

As previously established, UV radiation will degrade polymers such as polypropylene, polyester, and nylon over time. The rate at which each individual product specific polymer will degrade is a function of the quality and quantity of the protective additive utilized in the manufacturing process as well as the infield environmentally conditions, specifically the rate of solar radiation. In order to quantify the rate of UV degradation ASTM test method D-4355 is utilized, exposing product samples to intensive environmental conditions and testing the samples for strength retention after certain prescribed time periods.

These test results are then to be correlated with field performance to establish a base line acceleration factor for that specific product in that specific region and environment. Once the base line correlation is established, other regions can be developed by evaluating the difference in rate of solar radiation between regions. Unfortunately, the majority of products do not have sufficient data to properly correlate field performance to laboratory testing. Due to this lack of information, the industry has generally accepted the use of the previously established acceleration factor of 4.3 to correlate laboratory data to the environment in Arizona for a worst case scenario. Other regions and environmental conditions are then developed based on the difference in rate of solar radiation between Arizona and the region in question.

Table 4 establishes the percentage of the ultimate tensile strength retained after a set time of accelerated UV exposure. This UV degradation is also applied to the total coverage of the fully synthetic products as well as 5% coverage of the products utilizing organic material for coverage in order to account for the synthetic netting. Using the acceleration factor of 4.3, the data is generated for the products in question using Equation 1 through Equation 5 and the results are shown in Table 6 and Table 7.

Equation 1 calculates the tensile strength reduced by UV degradation.

$$\mathrm{T_{UVD}} = \mathrm{T_{ult}} - \mathrm{RF_{UVDT}} \quad (1)$$

Where $\mathrm{T_{UVD}}$ = Ultraviolet Reduced Tensile Strength

$\mathrm{T_{ult}}$ = Ultimate Tensile Strength

$\mathrm{RF_{UVDT}}$ = Tensile Strength Ultraviolet Reduction Factor

Equation 2 calculates the coverage reduced by UV degradation.

$$\mathrm{C_{UVD}} = \mathrm{C_{ult}} - \mathrm{RF_{UVDC}} \quad (2)$$

Where $\mathrm{C_{UVD}}$ = Ultraviolet Reduced Coverage

$\mathrm{C_{ult}}$ = Ultimate Coverage

$\mathrm{RF_{UVDC}}$ = Coverage Ultraviolet Reduction Factor

Equation 3 calculates the UV degradation reduction factor for tensile strength.

$$\mathrm{RF_{UVDT}} = \mathrm{T_{ult}} \cdot (1 - \mathrm{DF_{UV}}) \quad (3)$$

Where $\mathrm{RF_{UVDT}}$ = Tensile Strength Ultraviolet Reduction Factor

$\mathrm{T_{ult}}$ = Ultimate Tensile Strength

$\mathrm{DF_{UV}}$ = Ultraviolet Deceleration Factor

Equation 4 calculates the UV degradation reduction factor for coverage.

$$\mathrm{RF_{UVDC}} = \begin{Bmatrix} \mathrm{C_{ult}} \cdot (1 - \mathrm{DF_{UV}}); & \text{for Synthetic Material} \\ 0.05 \cdot (1 - \mathrm{DF_{UV}}); & \text{for Organic Material} \end{Bmatrix} \quad (4)$$

Where $\mathrm{RF_{UVDC}}$ = Coverage Ultraviolet Reduction Factor

C_{ult} = Ultimate Coverage

DF_{UV} = Ultraviolet Deceleration Factor

Equation 5 calculates the accelerated exposure time.

$$t_{AC} = t_{UV} \cdot AF_{UV} \quad (5)$$

Where t_{AC} = Accelerated Ultraviolet Exposure Duration

t_{UV} = Ultraviolet Exposure Duration

AF_{UV} = Ultraviolet Exposure Acceleration Factor

Table 6 presents the tensile strength of the listed GRECPs after UV degradation has been applied verses their respective accelerated exposure time.

Table 6 UV Degradation of Tensile Strength

Manufacturer / Distributor	Product Name	T_{ult} (lb/ft)	T_{UVD} (lb/ft)					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM	387.6	-	348.8	-	-	-	-
East Coast Erosion Control	ECC-3	802.0	-	786.0	-	-	-	-
	ECP-2	400.0	-	328.0	-	-	-	-
	ECSC-3	756.0	604.8	-	-	-	-	-
	T-RECS	3,000.0	-	-	-	-	2,730.0	-
North American Green	C350	625.0	-	537.5	-	-	-	-
	SC250	620.0	-	620.0	-	-	-	-
	W3000	3,600.0	-	-	-	2,880.0	-	-
Profile	Enkamat 7020	175.0	-	140.0	-	-	-	-
	Enkamat R45	3,000.0	-	-	2,400.0	-	-	-
Propex	Landlok 300	2,000.0	-	-	-	1,800.0	-	-
	Landlok 450	400.0	-	320.0	-	-	-	-
	Pyramat	4,000.0	-	-	-	-	3,600.0	3,400.0
Western Excelsior	Excel PP5-10	249.6	249.6	224.6	-	-	-	-
	PP5-Heavy Duty	2,500.0	2,500.0	-	-	2,250.0	-	-
	PP5-Xtreme	4,000.0	4,000.0	-	-	-	3,600.0	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

Table 7 presents the coverage of the listed GRECPs after UV degradation has been applied verses their respective accelerated exposure time.

Table 7 UV Degradation of Coverage

Manufacturer / Distributor	Product Name	C_{ult}	C_{UVD}					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM	45%	-	41%	-	-	-	-
East Coast Erosion Control	ECC-3*	86%	-	86%	-	-	-	-
	ECP-2	82%	-	67%	-	-	-	-
	ECSC-3*	93%	92%	-	-	-	-	-
	T-RECS	66%	-	-	-	-	60%	-
North American Green	C350*	91%	-	90%	-	-	-	-
	SC250*	81%	-	81%	-	-	-	-
	W3000	88%	-	-	-	70%	-	-
Profile	Enkamat 7020	5%	-	4%	-	-	-	-
	Enkamat R45	5%	-	-	4%	-	-	-
Propex	Landlok 300	65%	-	-	-	59%	-	-
	Landlok 450	80%	-	64%	-	-	-	-
	Pyramat	90%	-	-	-	-	81%	77%
Western Excelsior	Excel PP5-10	75%	75%	68%	-	-	-	-
	PP5-Heavy Duty	70%	70%	-	-	63%	-	-
	PP5-Xtreme	70%	70%	-	-	-	63%	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

* Synthetic netting is estimated to contribute 5% of the products overall coverage. Only product Coverage contributed by synthetic materials is affected by UV degradation.

Biological Degradation

GRECPs containing organic material are subject to some degree of biological degradation. When organic material is utilized within a GRECP it greatly contributes to the initial coverage but does not usually contribute much to the tensile strength of the product. As the biological degradation occurs, the coverage of

GRECPs utilizing organic material will reduce drastically. The organic materials that are typically used within GRECPs are straw, coconut, and a combination of the two.

It has been seen in the market place that most erosion control materials containing straw will be in place for around 1 year, while those containing coconut will be in place for around 3 years. It has also been seen that erosion control products containing a mixture of straw and coconut will be in place for 2 years. This is seen even further as manufactures of erosion control materials containing straw publish a design life of 1 year, those containing coconut publish a design life of 3 years, and those containing a combination of straw and coconut publish a design life of 2 years. While this could become extremely complex, there is no debate within the market place towards the temporary nature of straw and coconut.

As shown in Table 5, biological degradation will not affect the tensile strength of the fully synthetic products, but will affect all but 5% coverage of products utilizing organic material. Using the above assumptions, the data is generated for the products in question using Equation 6 through Equation 10 and the results are shown in Table 8 and Table 9.

Equation 6 calculates the tensile strength reduced by UV and biological degradation.

$$\mathrm{T_{UVD,BD}} = \mathrm{T_{UVD}} - \mathrm{RF_{BDT}} \quad (6)$$

Where $\mathrm{T_{UVD,BD}} = \text{Ultraviolet and Biological Reduced Tensile Strength}$

$\mathrm{T_{UVD}} = \text{Ultraviolet Reduced Tensile Strength}$

$\mathrm{RF_{BDT}} = \text{Tensile Strength Biological Reduction Factor}$

Equation 7 calculates the coverage reduced by UV and biological degradation.

$$\mathrm{C_{UVD,BD}} = \mathrm{C_{UVD}} - \mathrm{RF_{BDC}} \quad (7)$$

Where $\mathrm{C_{UVD,BD}} = \text{Ultraviolet and Biological Reduced Coverage}$

$\mathrm{C_{UVD}} = \text{Ultraviolet Reduced Coverage}$

$\mathrm{RF_{BDC}} = \text{Coverage Biological Reduction Factor}$

Equation 8 calculates the biological degradation reduction factor for tensile strength.

$$\mathrm{RF_{BDT}} = 0 \quad (8)$$

Where $\mathrm{RF_{BDT}} = \text{Tensile Strength Biological Reduction Factor}$

Equation 9 calculates the biological degradation reduction factor for coverage.

$$\mathrm{RF_{BDC}} = \begin{cases} 0; & \text{for Synthetic Material} \\ \frac{(\mathrm{C_{ult}} - 0.05)}{\mathrm{DF_{BDC}}} \cdot \mathrm{t_{AC}}\,; & \text{for Organic Material} \end{cases} \quad (9)$$

Where $\mathrm{RF_{BDC}} = \text{Coverage Biological Reduction Factor}$

$\mathrm{C_{ult}} = \text{Ultimate Coverage}$

$\mathrm{DF_{BDC}} = \text{Biological Deceleration Factor}$

$\mathrm{t_{AC}} = \text{Accelerated Ultraviolet Exposure Duration}$

Equation 10 calculates the biological degradation deceleration factor for coverage.

$$\mathrm{DF_{BDC}} = \begin{cases} 1; & \text{for Straw} \\ 2; & \text{for Straw/Coconut Blend} \\ 3; & \text{for Coconut} \end{cases} \quad (10)$$

Where $\mathrm{DF_{BDC}} = \text{Biological Deceleration Factor}$

Table 8 presents the tensile strength of the listed GRECPs after UV and biological degradation has been applied verses their respective accelerated exposure time.

Table 8 Biological Degradation of Tensile Strength

Manufacturer / Distributor	Product Name	T_{ult} (lb/ft)	$T_{UVD,BD}$ (lb/ft)					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM	387.6	-	348.8	-	-	-	-
East Coast Erosion Control	ECC-3*	802.0	-	786.0	-	-	-	-
	ECP-2	400.0	-	328.0	-	-	-	-
	ECSC-3*	756.0	604.8	-	-	-	-	-
	T-RECS	3,000.0	-	-	-	-	2,730.0	-
North American Green	C350*	625.0	-	537.5	-	-	-	-
	SC250*	620.0	-	620.0	-	-	-	-
	W3000	3,600.0	-	-	-	2,880.0	-	-
Profile	Enkamat 7020	175.0	-	140.0	-	-	-	-
	Enkamat R45	3,000.0	-	-	2,400.0	-	-	-
Propex	Landlok 300	2,000.0	-	-	-	1,800.0	-	-
	Landlok 450	400.0	-	320.0	-	-	-	-
	Pyramat	4,000.0	-	-	-	-	3,600.0	3,400.0
Western Excelsior	Excel PP5-10	249.6	249.6	224.6	-	-	-	-
	PP5-Heavy Duty	2,500.0	2,500.0	-	-	2,250.0	-	-
	PP5-Xtreme	4,000.0	4,000.0	-	-	-	3,600.0	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

* Synthetic material is estimated to contribute the majority of the products overall tensile strength. Only product tensile strength contributed by organic materials is affected by biological degradation.

Table 9 presents the coverage of the listed GRECPs after UV and biological degradation has been applied verses their respective accelerated exposure time.

Table 9 Biological Degradation of Coverage

Manufacturer / Distributor	Product Name	C_{ult}	$C_{UVD,BD}$					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM	45%	-	41%	-	-	-	-
East Coast Erosion Control	ECC-3*	86%	-	68%	-	-	-	-
	ECP-2	82%	-	67%	-	-	-	-
	ECSC-3*	93%	81%	-	-	-	-	-
	T-RECS	66%	-	-	-	-	60%	-
North American Green	C350*	91%	-	72%	-	-	-	-
	SC250*	81%	-	63%	-	-	-	-
	W3000	88%	-	-	-	70%	-	-
Profile	Enkamat 7020	5%	-	4%	-	-	-	-
	Enkamat R45	5%	-	-	4%	-	-	-
Propex	Landlok 300	65%	-	-	-	59%	-	-
	Landlok 450	80%	-	64%	-	-	-	-
	Pyramat	90%	-	-	-	-	81%	77%
Western Excelsior	Excel PP5-10	75%	75%	68%	-	-	-	-
	PP5-Heavy Duty	70%	70%	-	-	63%	-	-
	PP5-Xtreme	70%	70%	-	-	-	63%	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

* Organic material is estimated to contribute the majority of the products overall coverage. Only product coverage contributed by organic materials is affected by biological degradation.

Chemical Degradation

In addition to UV and biological degradation, some polymers have the potential to degrade at a chemical level. This can be seen in materials such as polyester and nylon in normally found environments. When exposed to moisture for a prolonged period of time, polyester and nylon will begin to absorb the moisture and break down at the molecular level. Similarly to the approach against UV degradation, materials can be protected against chemical degradation. However, little information is available regarding protection against chemical degradation or testing of this protection for GRECPs. While it is understood that chemical degradation of polyester and nylon GRECPs can occur, additional testing that is outside of the scope of this research is needed in order to provide further quantification. While no chemical degradation is applied, the data is generated for the products in question using Equation 11 through Equation 13 and the results are shown in Table 10 and Table 11.

Equation 11 calculates the tensile strength reduced by UV, biological, and chemical degradation

$$\mathrm{T_{UVD,BD,CD} = T_{UVD,BD} - RF_{CD}} \quad (11)$$

Where $\mathrm{T_{UVD,BD,CD}}$ = Ultraviolet, Biological, and Chemical Reduced Tensile Strength

$\mathrm{T_{UVD,BD}}$ = Ultraviolet and Biological Reduced Tensile Strength

$\mathrm{RF_{CD}}$ = Chemical Reduction Factor

Equation 12 calculates the coverage reduced by UV, biological, and chemical degradation

$$\mathrm{C_{UVD,BD,CD} = C_{UVD,BD} - RF_{CD}} \quad (12)$$

Where $\mathrm{C_{UVD,BD,CD}}$ = Ultraviolet, Biological, and Chemical Reduced Coverage

$\mathrm{C_{UVD,BD}}$ = Ultraviolet and Biological Reduced Coverage

$\mathrm{RF_{CD}}$ = Chemical Reduction Factor

Equation 13 calculates the chemical degradation reduction factor.

$$\mathrm{RF_{CD}} = 0 \quad (13)$$

Where $\mathrm{RF_{CD}}$ = Chemical Reduction Factor

Table 10 presents the tensile strength of the listed GRECPs after UV, biological, and chemical degradation has been applied verses their respective accelerated exposure time.

Table 10 Chemical Degradation of Tensile Strength

Manufacturer / Distributor	Product Name	T_{ult} (lb/ft)	$T_{UVD,BD,CD}$ (lb/ft)					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM	387.6	-	348.8	-	-	-	-
East Coast Erosion Control	ECC-3	802.0	-	786.0	-	-	-	-
	ECP-2	400.0	-	328.0	-	-	-	-
	ECSC-3	756.0	604.8	-	-	-	-	-
	T-RECS	3,000.0	-	-	-	-	2,730.0	-
North American Green	C350	625.0	-	537.5	-	-	-	-
	SC250	620.0	-	620.0	-	-	-	-
	W3000	3,600.0	-	-	-	2,880.0	-	-
Profile	Enkamat 7020	175.0	-	140.0	-	-	-	-
	Enkamat R45	3,000.0	-	-	2,400.0	-	-	-
Propex	Landlok 300	2,000.0	-	-	-	1,800.0	-	-
	Landlok 450	400.0	-	320.0	-	-	-	-
	Pyramat	4,000.0	-	-	-	-	3,600.0	3,400.0
Western Excelsior	Excel PP5-10	249.6	249.6	224.6	-	-	-	-
	PP5-Heavy Duty	2,500.0	2,500.0	-	-	2,250.0	-	-
	PP5-Xtreme	4,000.0	4,000.0	-	-	-	3,600.0	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

Table 11 presents the coverage of the listed GRECPs after UV, biological, and chemical degradation has been applied verses their respective accelerated exposure time.

Table 11 Chemical Degradation of Coverage

Manufacturer / Distributor	Product Name	C_{ult}	$C_{UVD,BD,CD}$					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM	45%	-	41%	-	-	-	-
East Coast Erosion Control	ECC-3	86%	-	68%	-	-	-	-
	ECP-2	82%	-	67%	-	-	-	-
	ECSC-3	93%	81%	-	-	-	-	-
	T-RECS	66%	-	-	-	-	60%	-
North American Green	C350	91%	-	72%	-	-	-	-
	SC250	81%	-	63%	-	-	-	-
	W3000	88%	-	-	-	70%	-	-
Profile	Enkamat 7020	5%	-	4%	-	-	-	-
	Enkamat R45	5%	-	-	4%	-	-	-
Propex	Landlok 300	65%	-	-	-	59%	-	-
	Landlok 450	80%	-	64%	-	-	-	-
	Pyramat	90%	-	-	-	-	81%	77%
Western Excelsior	Excel PP5-10	75%	75%	68%	-	-	-	-
	PP5-Heavy Duty	70%	70%	-	-	63%	-	-
	PP5-Xtreme	70%	70%	-	-	-	63%	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

Confidence due to Material Construction

The material construction of a GRECP can have a significant effect on not only the materials overall performance, but also on how the material will react to environmental stresses. Material construction types, such as stitch-bonded and heat-bonded GRECPs have the potential to be pulled apart by non-hydraulic stresses, causing them to cease functioning. The consistency and homogeneous nature of woven GRECPs removes this risk of failed stitching or delamination. In order to account for this lack of confidence, a reduction factor of 0.9 is applied to the tensile strength and coverage of the stitch-bonded and heat-bonded GRECPs. Using the above assumptions, the data is generated for the products in question using Equation 14 through Equation 16 and the results are shown in Table 12 and .

Equation 14 calculates the tensile strength reduced by UV, biological, and chemical degradation and confidence due to material construction.

$$\mathrm{T_{UVD,BD,CD,MC}} = \mathrm{T_{UVD,BD,CD}} \cdot \mathrm{RF_{MC}} \quad (14)$$

Where $\mathrm{T_{UVD,BD,CD,MC}}$ = Ultraviolet, Biological, Chemical, and Material Construction Reduced Tensile Strength

$\mathrm{T_{UVD,BD,CD}}$ = Ultraviolet, Biological, and Chemical Reduced Tensile Strength

$\mathrm{RF_{MC}}$ = Material Construction Reduction Factor

Equation 15 calculates the coverage reduced by UV, biological, and chemical degradation and confidence due to material construction.

$$\mathrm{C_{UVD,BD,CD,MC}} = \mathrm{C_{UVD,BD,CD}} \cdot \mathrm{RF_{MC}} \quad (15)$$

Where $\mathrm{C_{UVD,BD,CD,MC}}$ = Ultraviolet, Biological, Chemical, and Material Construction Reduced Coverage

$\mathrm{C_{UVD,BD,CD}}$ = Ultraviolet, Biological, and Chemical Reduced Coverage

$\mathrm{RF_{MC}}$ = Material Construction Reduction Factor

Equation 16 calculates the material construction reduction factor.

$$\mathrm{RF_{MC}} = \begin{cases} 0.9; & \text{Stitch} - \text{Bonded} \\ 0.9; & \text{Heat} - \text{Bonded} \\ 1.0; & \text{Woven} \end{cases} \quad (16)$$

Where $\mathrm{RF_{MC}}$ = Material Construction Reduction Factor

Table 12 presents the tensile strength of the listed GRECPs after UV, biological, and chemical degradation and confidence due to material construction has been applied verses their respective accelerated exposure time.

Table 12 Confidence in Tensile Strength due to Material Construction

Manufacturer / Distributor	Product Name	T_{ult} (lb/ft)	$T_{UVD,BD,CD,MC}$ (lb/ft)					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM *	348.8	-	314.0	-	-	-	-
East Coast Erosion Control	ECC-3 *	721.8	-	707.4	-	-	-	-
	ECP-2 *	360.0	-	295.2	-	-	-	-
	ECSC-3 *	680.4	544.3	-	-	-	-	-
	T-RECS	3,000.0	-	-	-	-	2,730.0	-
North American Green	C350 *	562.5	-	483.8	-	-	-	-
	SC250 *	558.0	-	558.0	-	-	-	-
	W3000	3,600.0	-	-	-	2,880.0	-	-
Profile	Enkamat 7020 *	157.5	-	126.0	-	-	-	-
	Enkamat R45 *	2,700.0	-	-	2,160.0	-	-	-
Propex	Landlok 300	2,000.0	-	-	-	1,800.0	-	-
	Landlok 450 *	360.0	-	288.0	-	-	-	-
	Pyramat	4,000.0	-	-	-	-	3,600.0	3,400.0
Western Excelsior	Excel PP5-10 *	224.6	224.6	202.2	-	-	-	-
	PP5-Heavy Duty	2,500.0	2,500.0	-	-	2,250.0	-	-
	PP5-Xtreme	4,000.0	4,000.0	-	-	-	3,600.0	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

* Reduction factor of 0.9 is applied to the tensile strength of stitch-bonded and heat-bonded GRECPs to account for material construction type.

Table 13 presents the coverage of the listed GRECPs after UV, biological, and chemical degradation and confidence due to material construction has been applied verses their respective accelerated exposure time.

Table 13 Confidence in Coverage due to Material Construction

Manufacturer / Distributor	Product Name	C_{ult}	$C_{UVD,BD,CD,MC}$					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM *	41%	-	36%	-	-	-	-
East Coast Erosion Control	ECC-3 *	77%	-	61%	-	-	-	-
	ECP-2 *	74%	-	61%	-	-	-	-
	ECSC-3 *	84%	73%	-	-	-	-	-
	T-RECS	66%	-	-	-	-	60%	-
North American Green	C350 *	82%	-	65%	-	-	-	-
	SC250 *	73%	-	57%	-	-	-	-
	W3000	88%	-	-	-	70%	-	-
Profile	Enkamat 7020 *	5%	-	4%	-	-	-	-
	Enkamat R45 *	5%	-	-	4%	-	-	-
Propex	Landlok 300	65%	-	-	-	59%	-	-
	Landlok 450 *	72%	-	58%	-	-	-	-
	Pyramat	90%	-	-	-	-	81%	77%
Western Excelsior	Excel PP5-10 *	68%	68%	61%	-	-	-	-
	PP5-Heavy Duty	70%	70%	-	-	63%	-	-
	PP5-Xtreme	70%	70%	-	-	-	63%	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

* Reduction factor of 0.9 is applied to the coverage of stitch-bonded and heat-bonded GRECPs to account for material construction type.

Confidence due to Material Quality

As previously established, the quality of manufacturing and testing of GRECPs can have a significant effect on the material's performance. Additionally, as we are using material properties and extrapolating potentially 20 to 50 years to determine the material's functional longevity, it is imperative that we have an appropriate confidence in those properties upon initial installation. Because there is a 50% confidence in a Typical value, a reduction factor of 0.5 is applied to the material's tensile strength and coverage. Since there is a 97.7% confidence in a MARV, a reduction factor of 0.977 is applied to the material's tensile strength and coverage. Using the above assumptions, the data is generated for the products in question using Equation 17 through Equation 20 and the results are shown in Table 14 and Table 15.

Equation 17 calculates the tensile strength reduced by UV, biological, and chemical degradation and confidence due to material construction and material quality.

$$\mathrm{T_{UVD,BD,CD,MC,MQT}} = \mathrm{T_{UVD,BD,CD,MC}} \cdot \mathrm{RF_{MQT}} \qquad (17)$$

Where $\mathrm{T_{UVD,BD,CD,MC,MQT}}$ = Ultraviolet, Biological, Chemical, Material Construction, and Material Quality Reduced Tensile Strength

$\mathrm{T_{UVD,BD,CD,MC}}$ = Ultraviolet, Biological, Chemical, and Material Construction Reduced Tensile Strength

$\mathrm{RF_{MQT}}$ = Tensile Strength Material Quality Reduction Factor

Equation 18 calculates the coverage reduced by UV, biological, and chemical degradation and confidence due to material construction and material quality.

$$\mathrm{C_{UVD,BD,CD,MC,MQT}} = \mathrm{C_{UVD,BD,CD,MC}} \cdot \mathrm{RF_{MQC}} \qquad (18)$$

Where $\mathrm{C_{UVD,BD,CD,MC,MQT}}$ = Ultraviolet, Biological, Chemical, Material Construction, and Material Quality Reduced Coverage

$\mathrm{C_{UVD,BD,CD,MC}}$ = Ultraviolet, Biological, Chemical, and Material Construction Reduced Coverage

$\mathrm{RF_{MQC}}$ = Coverage Material Quality Reduction Factor

Equation 19 calculates the material quality tensile strength reduction factor.

$$\mathrm{RF_{MQT}} = \begin{Bmatrix} 0.500; & \text{Typical Value} \\ 0.977; & \text{MARV} \end{Bmatrix} \qquad (19)$$

Where $\mathrm{RF_{MQT}} = \text{Tensile Strength Material Quality Reduction Factor}$

Equation 20 calculates the material quality coverage reduction factor.

$$\mathrm{RF_{MQC}} = \begin{Bmatrix} 0.500; & \text{Typical Value} \\ 0.977; & \text{MARV} \end{Bmatrix} \quad (20)$$

Where $\mathrm{RF_{MQC}} = \text{Coverage Material Quality Reduction Factor}$

Table 14 presents the tensile strength of the listed GRECPs after UV, biological, and chemical degradation and confidence due to material construction and material quality has been applied verses their respective accelerated exposure time.

Table 14 Confidence in Tensile Strength due to Material Quality

Manufacturer / Distributor	Product Name	T_{ult} (lb/ft)	$T_{UVD,BD,CD,MC,MQT}$ (lb/ft)					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM [1]	174.4	-	157.0	-	-	-	-
East Coast Erosion Control	ECC-3 [1]	360.9	-	353.7	-	-	-	-
	ECP-2 [1]	180.0	-	147.6	-	-	-	-
	ECSC-3 [1]	340.2	272.2	-	-	-	-	-
	T-RECS [2]	2,931.0	-	-	-	-	2,667.2	-
North American Green	C350 [1]	281.3	-	241.9	-	-	-	-
	SC250 [1]	279.0	-	279.0	-	-	-	-
	W3000 [1]	1,800.0	-	-	-	1,440.0	-	-
Profile	Enkamat 7020 [2]	153.9	-	123.1	-	-	-	-
	Enkamat R45 [2]	2,637.9	-	-	2,110.3	-	-	-
Propex	Landlok 300 [2]	1,954.0	-	-	-	1,758.6	-	-
	Landlok 450 [1]	180.0	-	144.0	-	-	-	-
	Pyramat [2]	3,908.0	-	-	-	-	3,517.2	3,321.8
Western Excelsior	Excel PP5-10 [1]	112.3	112.3	101.1	-	-	-	-
	PP5-Heavy Duty [2]	2,442.5	2,442.5	-	-	2,198.3	-	-
	PP5-Xtreme [2]	3,908.0	3,908.0	-	-	-	3,517.2	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

1 - Reduction factor of 0.5 is applied to the tensile strength of the material to account for material quality.
2 – Reduction factor of 0.977 is applied to the tensile strength of the material to account for material quality.

Table 15 presents the coverage of the listed GRECPs after UV, biological, and chemical degradation and confidence due to material construction and material quality has been applied verses their respective accelerated exposure time.

Table 15 Confidence in Coverage due to Material Quality

Manufacturer / Distributor	Product Name	C_{ult}	$C_{UVD,BD,CD,MC,MQC}$					
			500 hrs	1,000 hrs	2,000 hrs	3,000 hrs	6,000 hrs	10,000 hrs
American Excelsior	Recyclex TRM [1]	20%	-	18%	-	-	-	-
East Coast Erosion Control	ECC-3 [1]	39%	-	30%	-	-	-	-
	ECP-2 [1]	37%	-	30%	-	-	-	-
	ECSC-3 [1]	42%	36%	-	-	-	-	-
	T-RECS [1]	33%	-	-	-	-	30%	-
North American Green	C350 [1]	41%	-	32%	-	-	-	-
	SC250 [1]	36%	-	29%	-	-	-	-
	W3000 [1]	44%	-	-	-	35%	-	-
Profile	Enkamat 7020 [1]	2%	-	2%	-	-	-	-
	Enkamat R45 [1]	2%	-	-	2%	-	-	-
Propex	Landlok 300 [2]	64%	-	-	-	57%	-	-
	Landlok 450 [1]	36%	-	29%	-	-	-	-
	Pyramat [2]	88%	-	-	-	-	79%	75%
Western Excelsior	Excel PP5-10 [1]	34%	34%	30%	-	-	-	-
	PP5-Heavy Duty [1]	35%	35%	-	-	32%	-	-
	PP5-Xtreme [1]	35%	35%	-	-	-	32%	-
t_{AC}			2,150 hrs	4,300 hrs	8,600 hrs	12,900 hrs	25,800 hrs	43,000 hrs
			0.25 yrs	0.50 yrs	1.00 yrs	1.49 yrs	2.99 yrs	4.98 yrs

1 - Reduction factor of 0.5 is applied to the coverage of the material to account for material quality.
2 – Reduction factor of 0.977 is applied to the coverage of the material to account for material quality.

Evaluate Results

With the data gathered on the GRECPs in question and the appropriate degradation applied, the tensile strength and coverage is then plotted against time in order to establish a trend, or degradation curve for each material. Exponential curves are used to fit the data and are extended in order to extrapolate the degradation. The reduction in tensile strength and coverage is compared to the functional threshold of 1,000 lbs/ft and 20% respectively for HPTRMs and 100 lbs/ft and 10% respectively for TRMs. The point in time where the material's estimated tensile strength or coverage reduces below the above mentioned functional threshold is determined as their functional longevity for this set of environmental conditions. The functional longevity graphs are generated for the products in question using Equation 21 and Equation 22 and shown in Figure 1 through Figure 16.

The functional tensile strength is obtained using Equation 21, which utilizes all of the established reduction factors.

$$T_F = T_{UVD,BD,CD,MC,MQT} = [T_{ult} - RF_{UVDT} - RF_{BDT} - RF_{CD}] \cdot RF_{MC} \cdot RF_{MQT} \quad (21)$$

Where $T_F = \text{Functional Tensile Strength}$

$T_{UVD,BD,CD,MC,MQT} = \text{Ultraviolet, Biological, Chemical, Material Construction, and Material QualityReduced Tensile Strength}$

$T_{ult} = \text{Ultimate Tensile Strength}$

$RF_{UVDT} = \text{Tensile Strength Ultraviolet Reduction Factor}$

$RF_{BDT} = \text{Tensile Strength Biological Reduction Factor}$

$RF_{CD} = \text{Chemical Reduction Factor}$

$RF_{MC} = \text{Material Construction Reduction Factor}$

$RF_{MQT} = \text{Tensile Strength Material Quality Reduction Factor}$

The functional coverage is obtained using Equation 22, which utilizes all of the established reduction factors.

$$C_F = C_{UVD,BD,CD,MC,MQC} = [C_{ult} - RF_{UVDC} - RF_{BDC} - RF_{CD}] \cdot RF_{MC} \cdot RF_{MQC} \quad (22)$$

Where $C_F = \text{Functional Coverage}$

$C_{UVD,BD,CD,MC,MQC} = \text{Ultraviolet, Biological, Chemical, Material Construction, and Material}$

Quality Reduced Coverage

C_{ult} = Ultimate Coverage

RF_{UVDC} = Coverage Ultraviolet Reduction Factor

RF_{BDC} = Coverage Biological Reduction Factor

RF_{CD} = Chemical Reduction Factor

RF_{MC} = Material Construction Reduction Factor

RF_{MQC} = Coverage Material Quality Reduction Factor

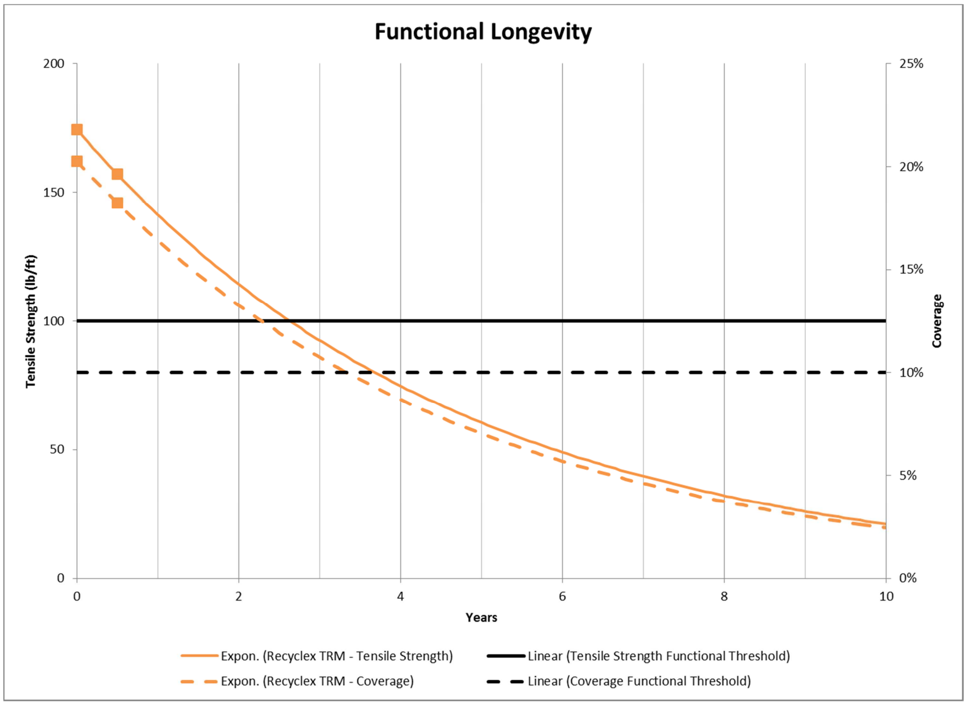

Figure 1 Functional Longevity of Recyclex TRM

From Figure 1 it can be seen that the anticipated tensile strength of Recyclex TRM reduces below the functional threshold at around 2.5 years while the anticipated coverage of Recyclex TRM reduces below the functional threshold at around 3.5 years. Taking the lesser of the two a functional longevity of 2.5 years is established for Recyclex TRM.

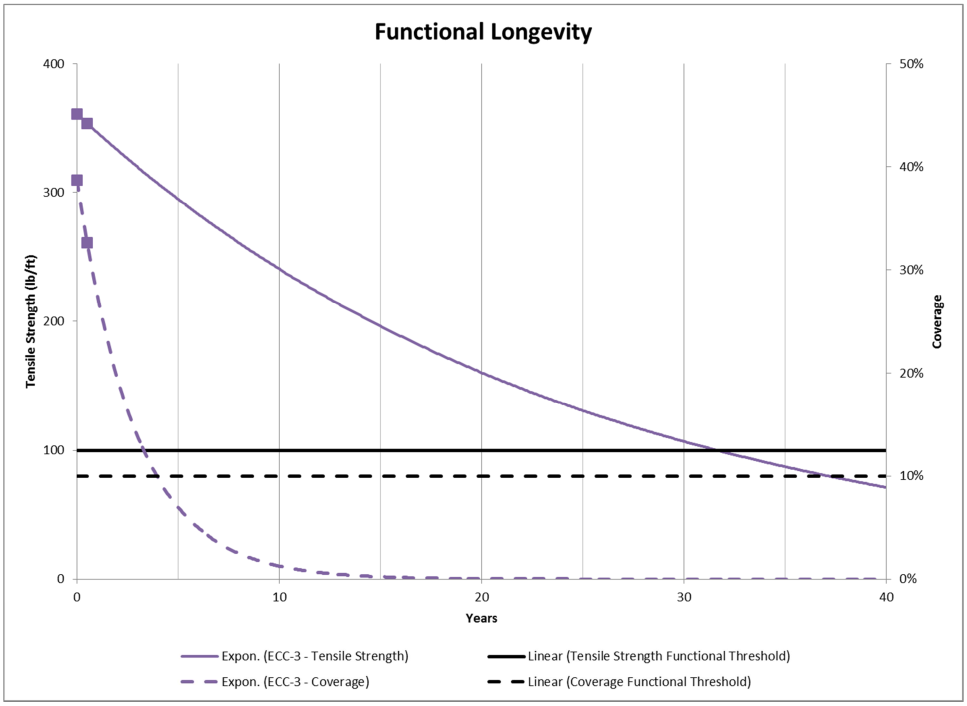

Figure 2 Functional Longevity of ECC-3

From Figure 2 it can be seen that the anticipated tensile strength of ECC-3 reduces below the functional threshold at around 30 years while the anticipated coverage of ECC-3 reduces below the functional threshold at around 4 years. Taking the lesser of the two a functional longevity of 4 years is established for ECC-3.

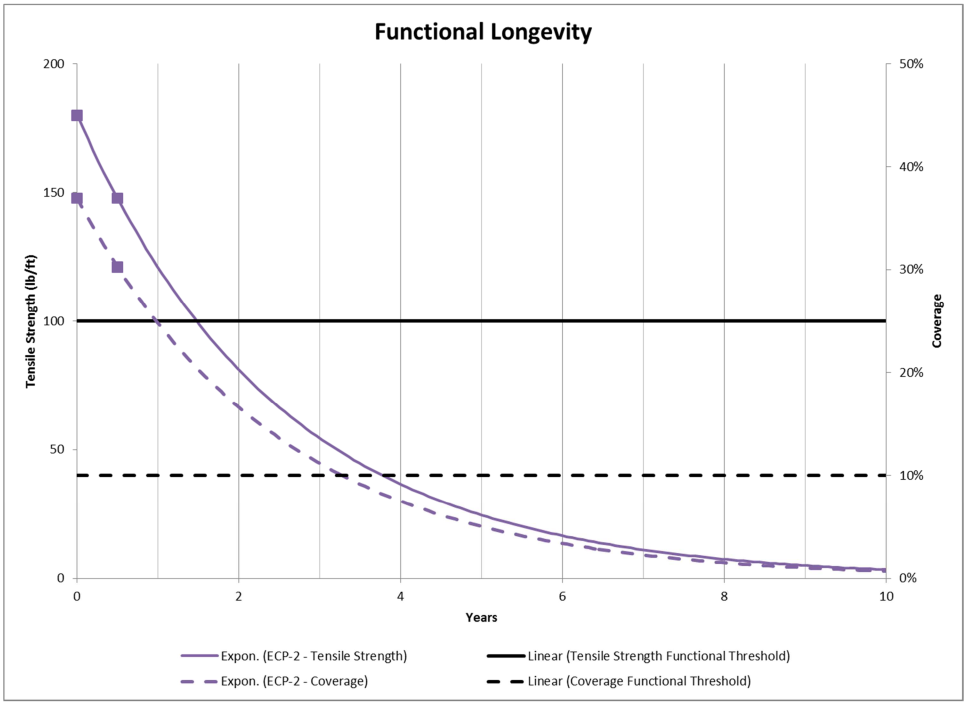

Figure 3 Functional Longevity of ECP-2

From Figure 3 it can be seen that the anticipated tensile strength of ECP-2 reduces below the functional threshold at around 1.5 years while the anticipated coverage of ECP-2 reduces below the functional threshold at around 3.5 years. Taking the lesser of the two a functional longevity of 1.5 years is established for ECP-2.

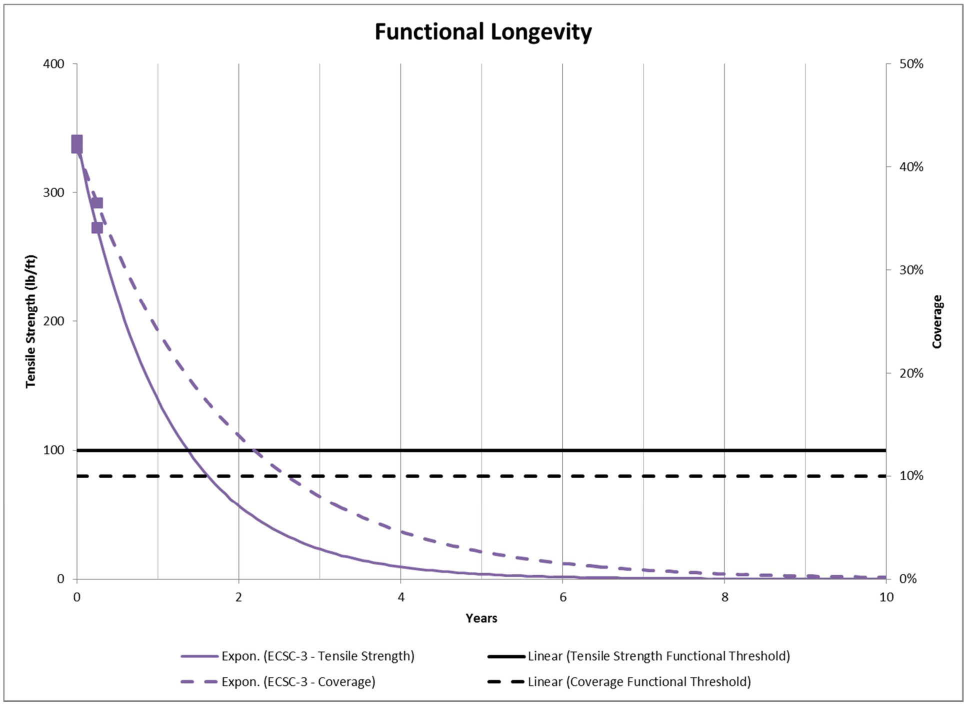

Figure 4 Functional Longevity of ECSC-3

From Figure 4 it can be seen that the anticipated tensile strength of ECSC-3 reduces below the functional threshold at around 1.5 years while the anticipated coverage of ECSC-3 reduces below the functional threshold at around 2.5 years. Taking the lesser of the two a functional longevity of 1.5 years is established for ECSC-3.

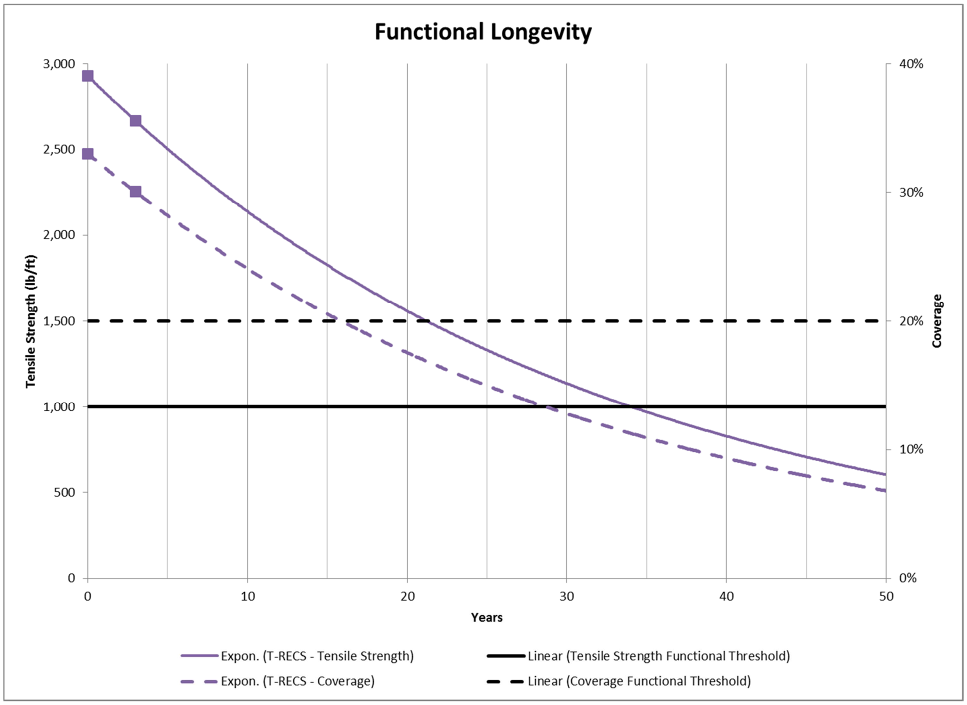

Figure 5 Functional Longevity of T-RECS

From Figure 5 it can be seen that the anticipated tensile strength of T-RECS reduces below the functional threshold at around 35 years while the anticipated coverage of T-RECS reduces below the functional threshold at around 15 years. Taking the lesser of the two a functional longevity of 15 years is established for T-RECS.

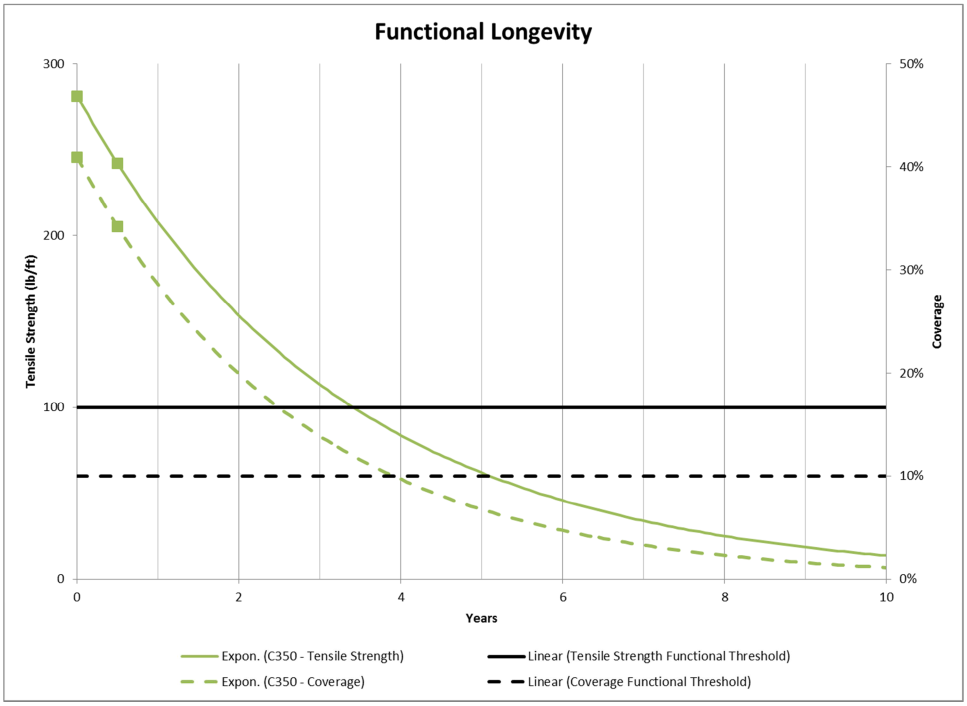

Figure 6 Functional Longevity of C350

From Figure 6 it can be seen that the anticipated tensile strength of C350 reduces below the functional threshold at around 3.5 years while the anticipated coverage of C350 reduces below the functional threshold at around 4 years. Taking the lesser of the two a functional longevity of 3.5 years is established for C350.

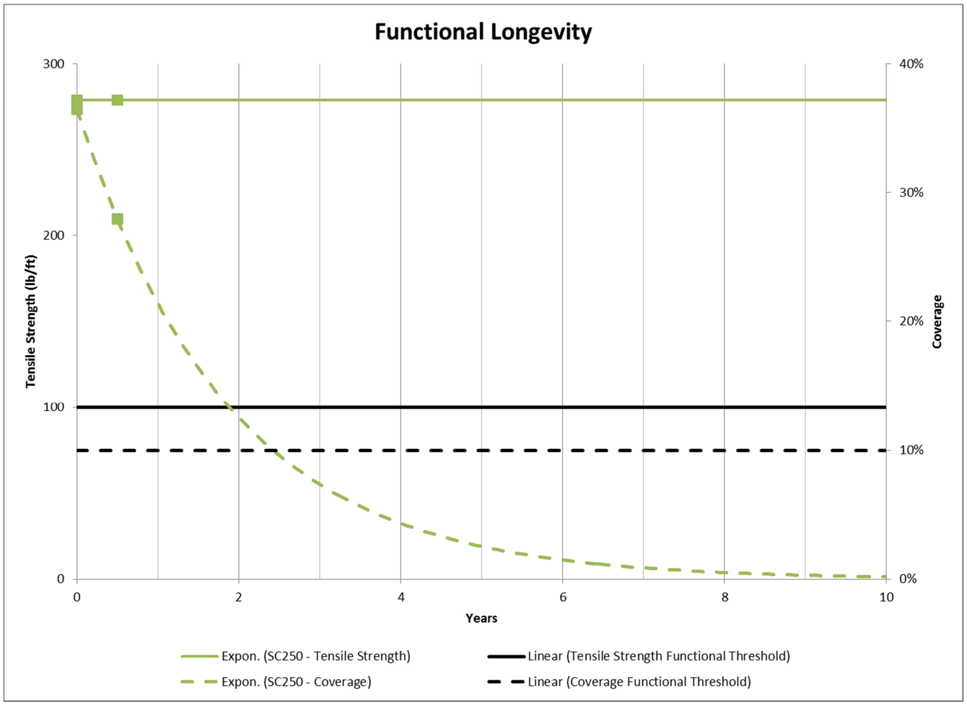

Figure 7 Functional Longevity of SC250

From Figure 7 it can be seen that the anticipated tensile strength of SC250 does not reduce in a realistic manner due to the lack of published information on UV resistance and is therefore disregarded until additional data can be presented. It can also be seen the anticipated coverage of SC250 reduces below the functional threshold at around 3.5 years. Taking the lesser of the two a functional longevity of 3.5 years is established for C350.

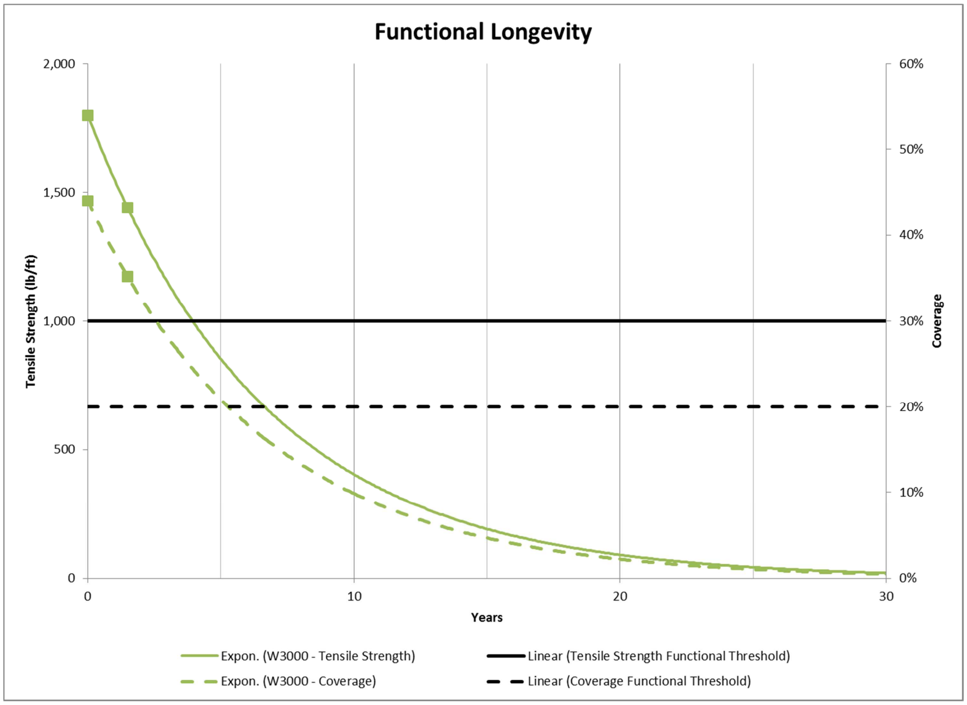

Figure 8 Functional Longevity of W3000

From Figure 8 it can be seen that the anticipated tensile strength of W3000 reduces below the functional threshold at around 4 years while the anticipated coverage of W3000 reduces below the functional threshold at around 5 years. Taking the lesser of the two a functional longevity of 4 years is established for W3000.

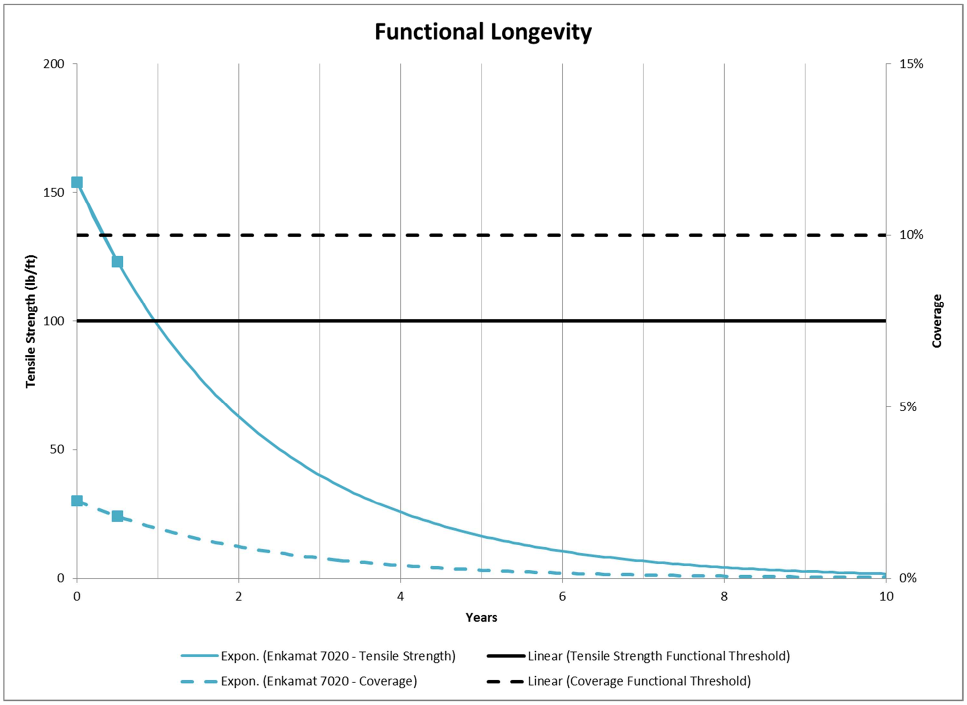

Figure 9 Functional Longevity of Enkamat 7020

From Figure 9 it can be seen that the anticipated tensile strength of Enkamat 7020 reduces below the functional threshold at around 1 year while the coverage of Enkamat 7020 does not ever surpass the functional threshold. Taking the lesser of the two a functional longevity of 1 years is established for Enkamat 7020.

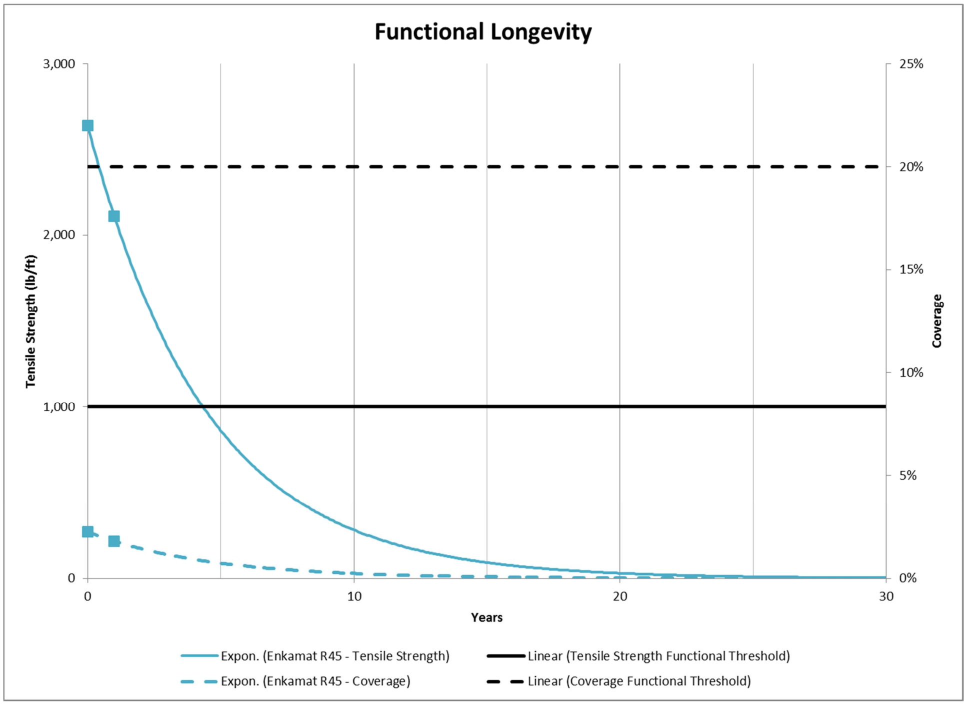

Figure 10 Functional Longevity of Enkamat R45

From Figure 10 it can be seen that the anticipated tensile strength of Enkamat R45 reduces below the functional threshold at around 1 year while the coverage of Enkamat R45 does not ever surpass the functional threshold. Taking the lesser of the two a functional longevity of 4 years is established for Enkamat R45.

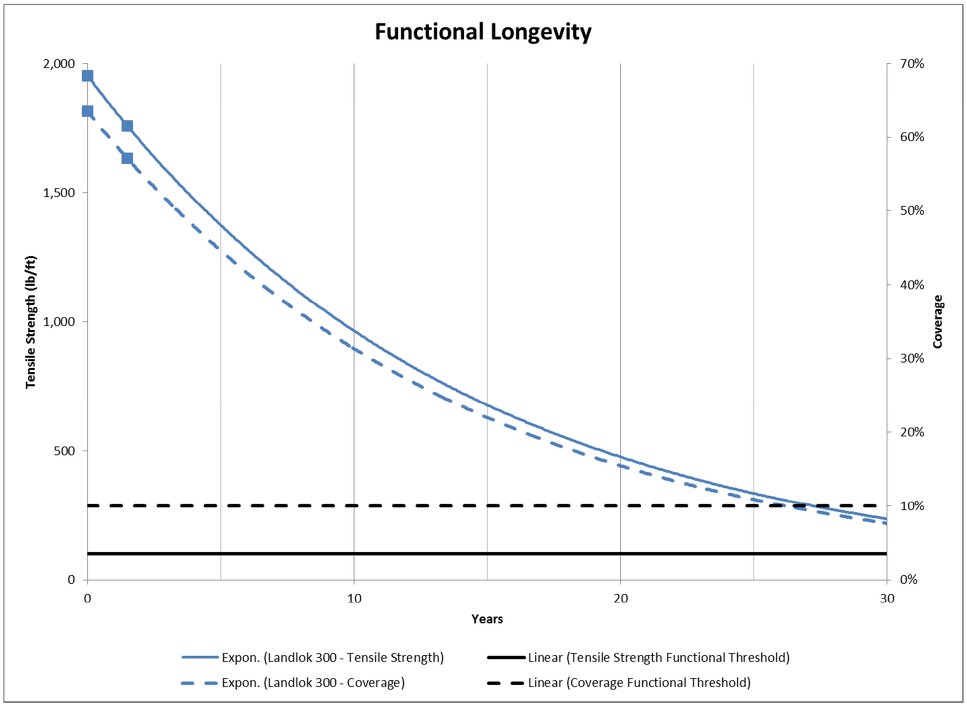

Figure 11 Functional Longevity of Landlok 300

From Figure 11 it can be seen that the anticipated tensile strength of Landlok 300 reduces below the functional threshold at around 30 years while the anticipated coverage of Landlok 300 reduces below the functional threshold at around 25 years. Taking the lesser of the two a functional longevity of 25 years is established for Landlok 300.

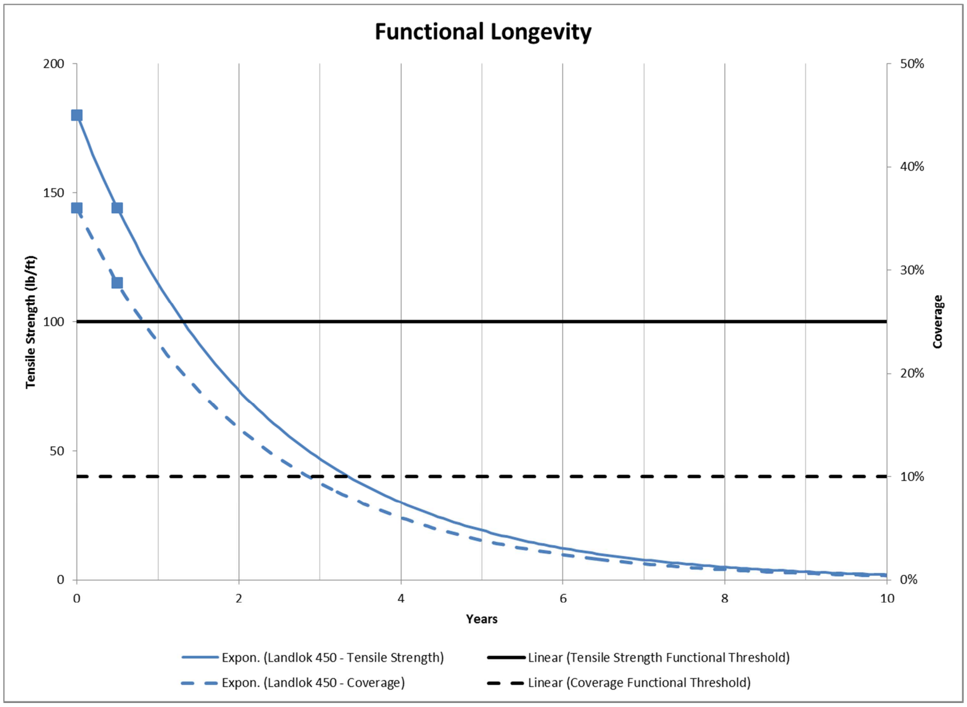

Figure 12 Functional Longevity of Landlok 450

From Figure 12 it can be seen that the anticipated tensile strength of Landlok 450 reduces below the functional threshold at around 1.5 years while the anticipated coverage of Landlok 450 reduces below the functional threshold at around 3 years. Taking the lesser of the two a functional longevity of 1.5 years is established for Landlok 450.

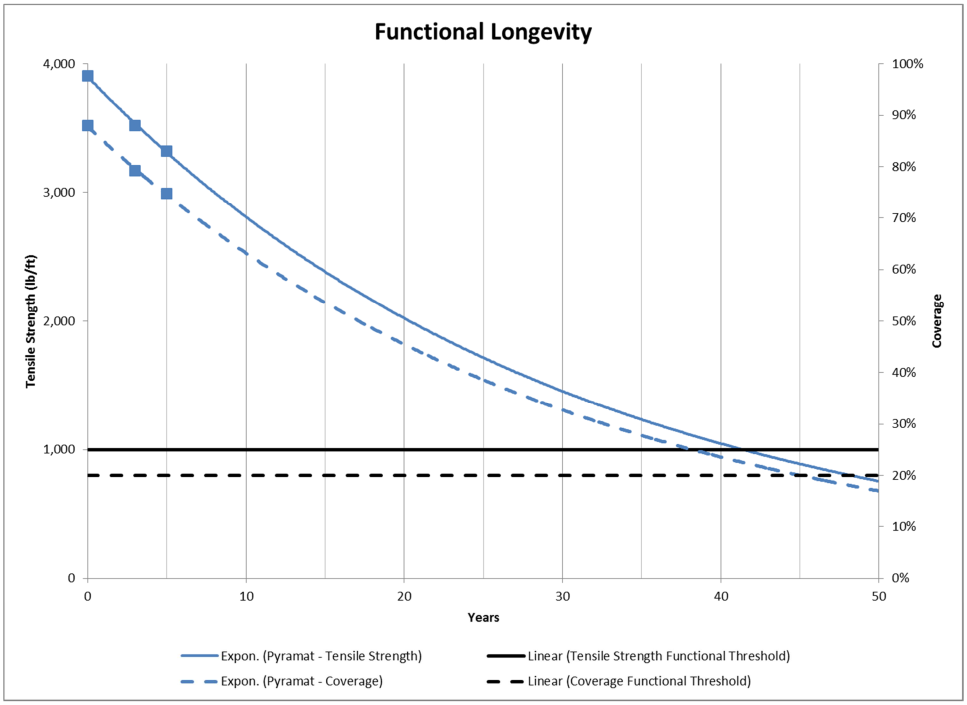

Figure 13 Functional Longevity of Pyramat

From Figure 13 it can be seen that the anticipated tensile strength of Pyramat reduces below the functional threshold at around 40 years while the anticipated coverage of Pyramat reduces below the functional threshold at around 45 years. Taking the lesser of the two a functional longevity of 40 years is established for Pyramat.

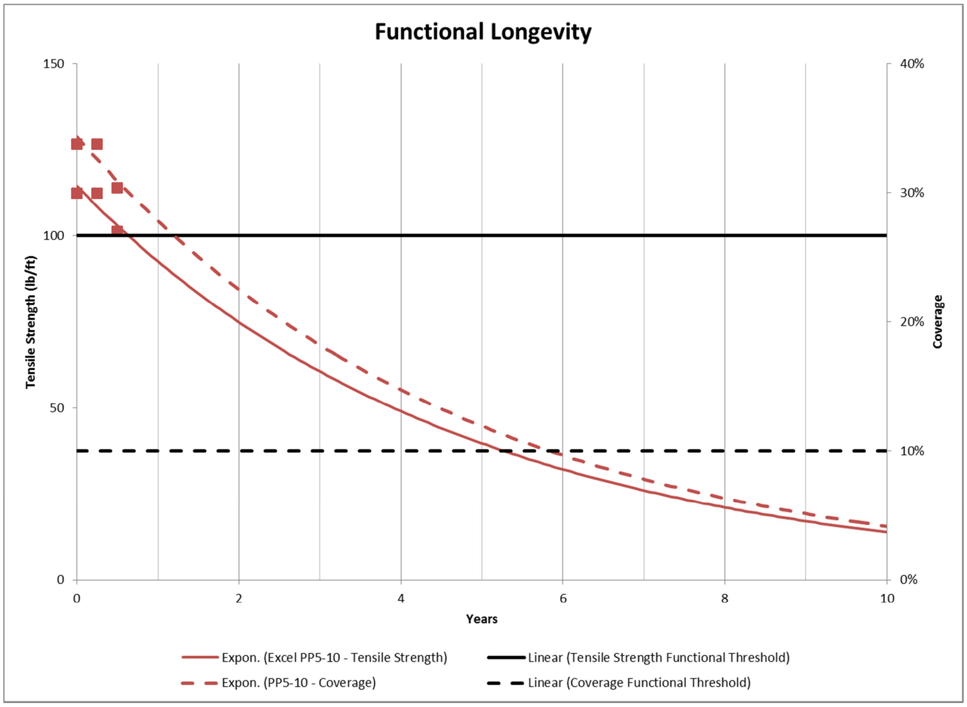

Figure 14 Functional Longevity of Excel PP5-10

From Figure 14 it can be seen that the anticipated tensile strength of Excel PP5-10 reduces below the functional threshold at around 0.5 years while the anticipated coverage of Excel PP5-10 reduces below the functional threshold at around 6 years. Taking the lesser of the two a functional longevity of 0.5 years is established for Excel PP5-10.

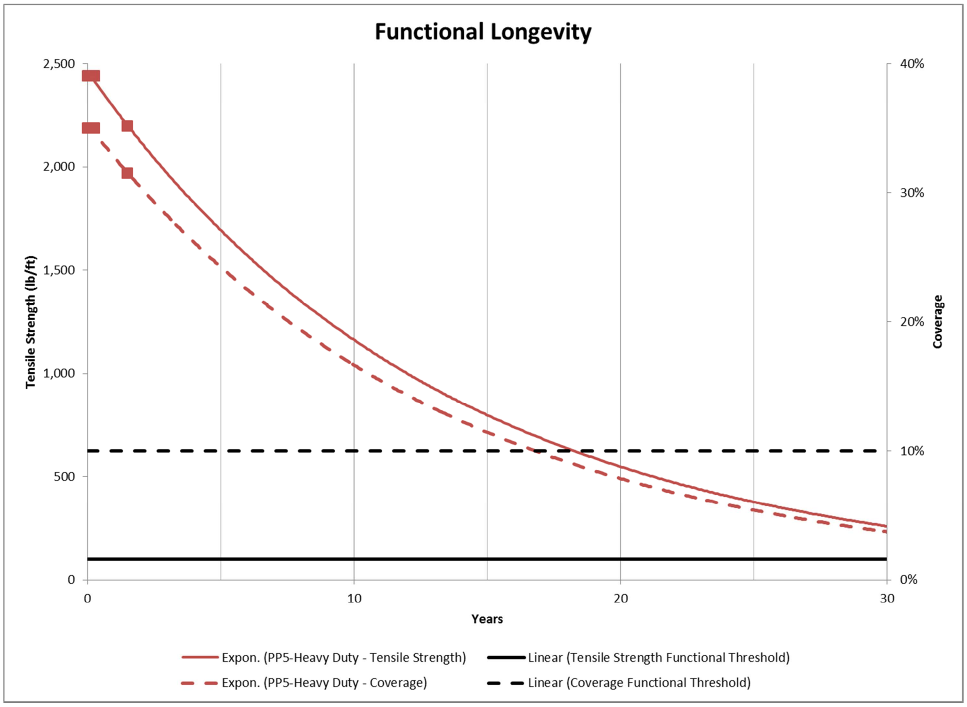

Figure 15 Functional Longevity of PP5-Heavy Duty

From Figure 15 it can be seen that the anticipated tensile strength of PP5-Heavy Duty reduces below the functional threshold at around 30 years while the anticipated coverage of PP5-Heavy Duty reduces below the functional threshold at around 15 years. Taking the lesser of the two a functional longevity of 15 years is established for PP5-Heavy Duty.

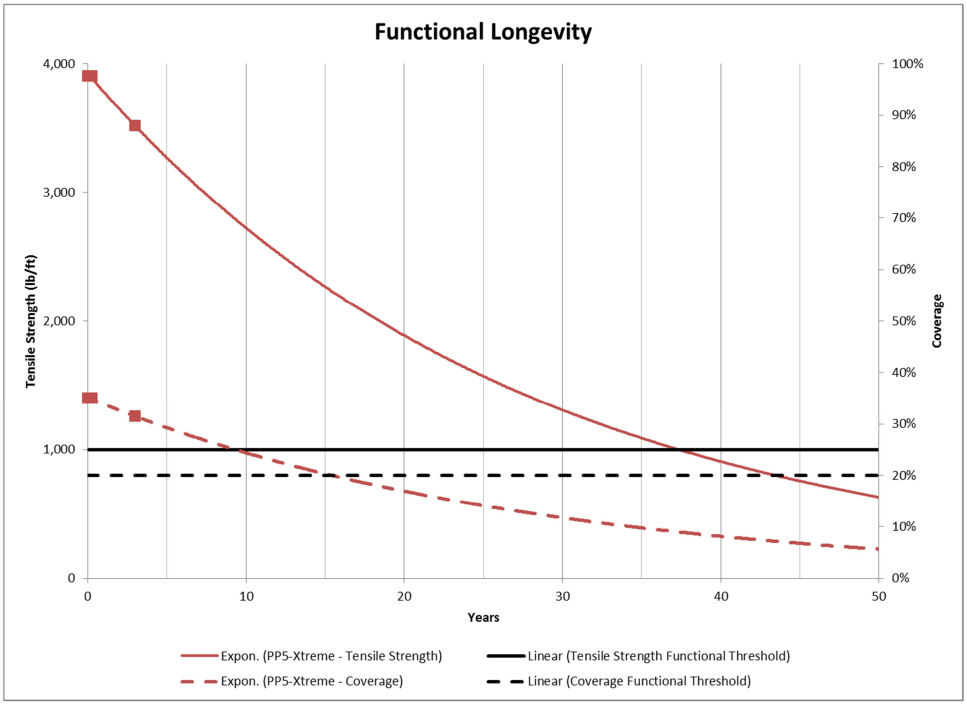

Figure 16 Functional Longevity of PP5-Xtreme

From Figure 16 it can be seen that the anticipated tensile strength of PP5-Xtreme reduces below the functional threshold at around 35 years while the anticipated coverage of PP5-Xtreme reduces below the functional threshold at around 15 years. Taking the lesser of the two a functional longevity of 15 years is established for PP5-Xtreme.

By evaluating each product and comparing the degradation of the material's tensile strength and coverage with the respective functional thresholds the GRECPs functional longevity is determined by the lesser value and is shown as the overall value in Table 16.

Table 16 GRECP Functional Longevity

Manufacturer / Distributor	Product Name	Functional Longevity		
		Tensile Strength	Coverage	Overall
American Excelsior	Recyclex TRM	< 3 years	< 4 years	< 3 years
East Coast Erosion Control	ECC-3	< 30 years	< 4 years	< 4 years
	ECP-2	< 2 years	< 4 years	< 2 years
	ECSC-3	< 2 years	< 3 years	< 2 years
	T-RECS	< 35 years	< 15 years	< 15 years
North American Green	C350	< 4 years	< 4 years	< 4 years
	SC250	N/A*	< 4 years	< 4 years
	W3000	< 4 years	< 5 years	< 4 years
Profile	Enkamat 7020	< 1 years	< 1 years	< 1 years
	Enkamat R45	< 4 years	< 1 years	< 1 years
Propex	Landlok 300	< 30 years	< 25 years	< 25 years
	Landlok 450	< 2 years	< 3 years	< 2 years
	Pyramat	< 40 years	< 45 years	< 40 years
Western Excelsior	Excel PP5-10	< 1 years	< 6 years	< 1 years
	PP5-Heavy Duty	< 30 years	< 15 years	< 15 years
	PP5-Xtreme	< 35 years	< 15 years	< 15 years

* Additional information required for further analysis.

Field Evaluations - Case Studies

The bases for the above established analysis is the industry accepted correlation factor of 4.3 (Koerner, Hsuan, & Koerner, 2011) for the UV degradation test data. While the biological and chemical degradation as well as the material construction and material quality reduction factors are generally applied based on overall product characteristics, the UV degradation is developed from product specific testing. To further refine the analysis, two case studies are presented in order to validate the amount of degradation anticipated in the above functional longevity analysis and then correlate the UV degradation data and establish product specific correlation factors.

Bell Road Channel Protection - Pyramat HPTRM

In the spring of 2002, the city of Scottsdale, Arizona was considering various means of protection for a channel beginning at Bell Road and running parallel to the Pima Freeway (Highway 101). The Bell Road channel spanned 2,500 ft, having a 46 ft bottom width, 2 Horizontal : 1 Vertical (2H:1V) side slopes, and 4 ft depth. The city of Scottsdale was in need of an aesthetic, cost-effective alternative to hard armoring such as rock riprap or concrete that was able to withstand hydraulic events generating velocities of up to 12 ft/s and shear stresses of up to 4 lb/ft^2 (Figure 17). The alternative solution would also have to be adequately durable in order to withstand potential non-hydraulic stresses from maintenance vehicles, channel debris, and burrowing animals. Due to the high solar radiation of the region, a high level of UV resistance was needed in order to sustain the required durability.

Figure 17 Bell Road Channel Initial Conditions

The Pyramat HPTRM was chosen by the city of Scottsdale to armor the Bell Road Channel in order to meet the required design criteria. In the fall of 2002, the Pyramat was installed along the Bell Road Channel (Figure 18). The plan for vegetation establishment consisted of hydroseeding with native desert plants with no plan for irrigation.

Figure 18 Bell Road Channel Pyramat Installation (Left) and Hydroseeding (Right) in 2002

Throughout the life of the project, the native desert plants continued to establish but never achieved coverage greater than 40% (Figure 19). This means that since 2002, over 60% of the Pyramat was exposed to extreme UV radiation.

Figure 19 Bell Road Channel Pyramat with Vegetation Establishment in 2005 (Left) and 2008 (Right)

In the spring of 2015, the Bell Road Channel was visited to evaluate the current performance (Figure 20). While the Pyramat was seen to be performing well there was still over 60% of the material fully exposed. While on site, samples were taken in order to evaluate the degradation over the past 13 years of exposure where local solar radiation is 21.70 MJ/m^2-day. The samples were taken from locations of obvious exposure where vegetation had never established in order to obtain the worst case scenario.

Figure 20 Bell Road Channel Pyramat with Continued Performance in 2015

In total, 5 samples were taken from the site to test for retained tensile strength per ASTM D-6818. Each sample yielded 5 individual tests, giving a total of 25 tensile strength tests. The tensile strength test results of the Pyramat showed an average tensile strength of 4,275.3 lbs/ft with a standard deviation of 551.8 lbs/ft, yielding a MARV of 3,171.7 lbs/ft with 79.3% strength retention over 155 months (APPENDIX B). When plotted against the original functional longevity graph for Pyramat we can confirm that using an acceleration factor of 4.3 is a conservative approach for predicting the durability of the Pyramat (Figure 21).

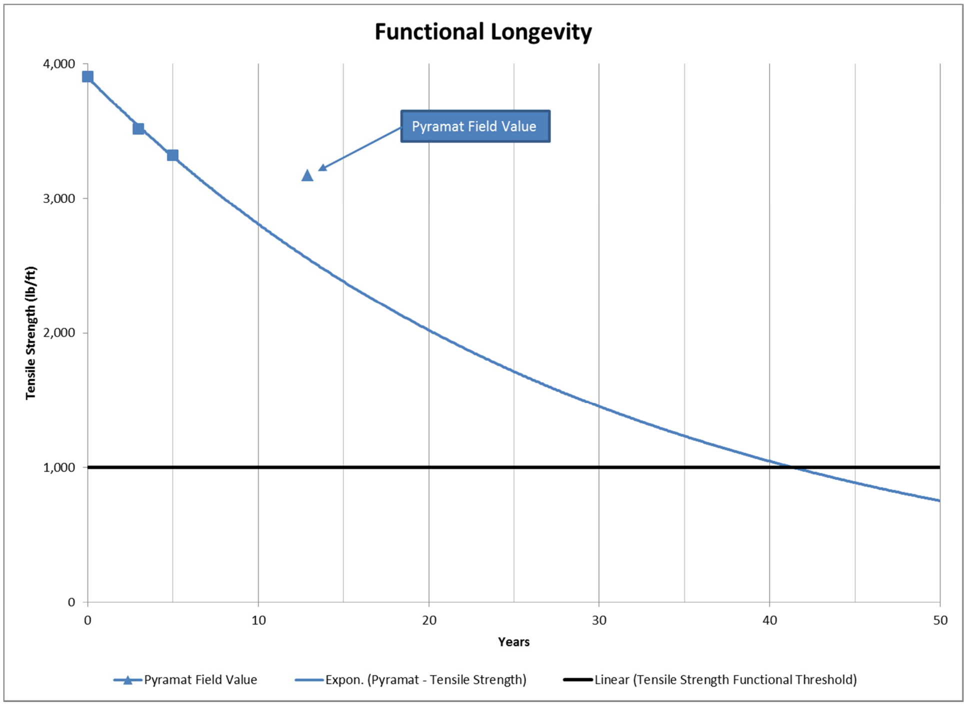

Figure 21 Pyramat Functional Longevity with Field Value

When compared to laboratory UV testing, 79.3% strength retention corresponds to an exposure time of 25.8 months, giving an acceleration factor of 6.0. Applying this field correlated acceleration factor for Pyramat along with the previously established modes of degradation the functional longevity graph is generated using the laboratory test data and field values and is shown in Figure 22.

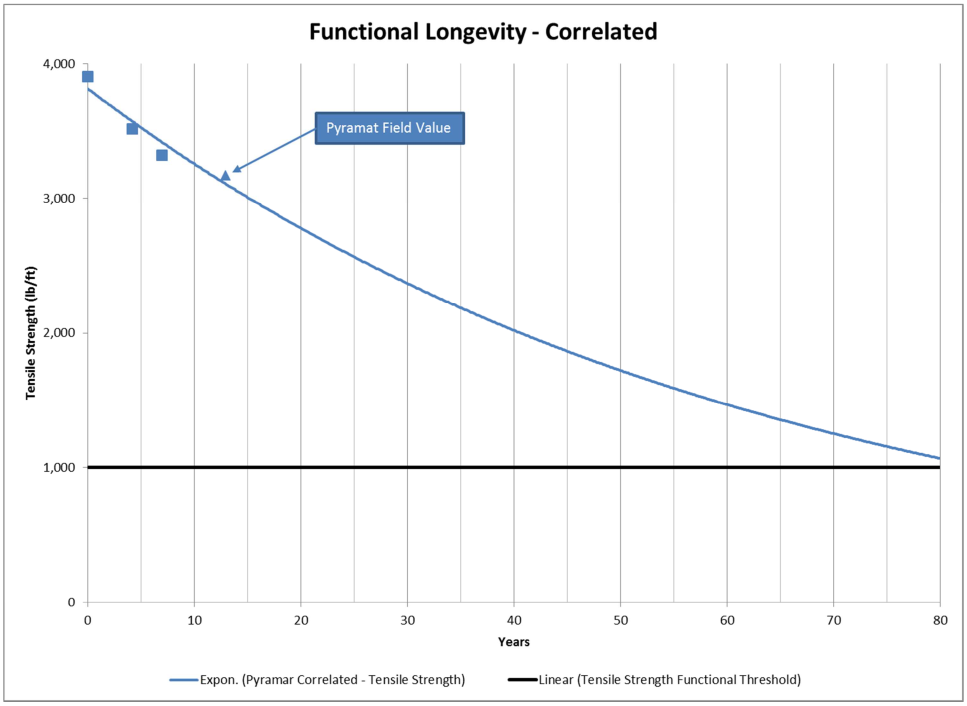

Figure 22 Correlated Functional Longevity of Pyramat

The inclusion of the field correlated acceleration factor increases the functional longevity of Pyramat from <40 years to <80 years based on tensile strength while showing proven performance for over 13 years in a high solar radiation environment.

Collas Road Slope Protection – PP5-Xtreme HPTRM

During the construction and movement of Mariscal Sucre international Airport in Quito, Ecuador extremely steep slopes were cut into the mountainside in order to create Collas Road. Collas Road was developed in order to provide easier and faster transport to and from the airport. Because of the potential erodibility of the site's soils, slope protection was needed and due to the high solar radiation of the region, a solution with a high level of UV resistance was required.

The PP5-Xtreme HPTRM was chosen to protect the Collas Road Slopes in order to meet the required design criteria. In May of 2013, the PP5-Xtreme was installed along the Collas Road Slopes (Figure 23). There was no plan for vegetation establishment and long term performance was to be provided solely by the PP5-Xtreme.

Figure 23 Collas Road Slope PP5-Xtreme Installation 2013

Since the installation in 2013 minimal vegetation has established providing no coverage (Figure 24). This means that during the 2 years of project life, 100% of the PP5-Xtreme has been exposed to extreme UV radiation.

Figure 24 Collas Road Slope PP5-Xtreme with Premature Oxidation 2014

In November of 2014, the Collas Road Slopes were visited to evaluate the current performance (Figure 25). It could be seen that the PP5-Xtreme was still fully exposed and had begun to change colors from a dark green color upon initial installation to a grey-blue color. A color change such as this is a sign of premature oxidation of the polymer. Samples were provided in order to evaluate the degradation over the past 18 months of exposure where local solar radiation is 19.73 MJ/m^2-day.

Figure 25 Collas Road Slope Color Change due to Oxidation

The material was tested for retained tensile strength per ASTM D-6818, yielding 5 individual tests. The tensile strength test results of the PP5-Xtreme showed an average tensile strength of 3,029.1 lbs/ft with a standard deviation of 195.4 lbs/ft, yielding a MARV of 2,638.2 lbs/ft with 66.0% strength retention over 18 months (Figure 45). When plotted against the original functional longevity graph for PP5-Xtreme we can see that using an acceleration factor of 4.3 is not an appropriate approach for predicting the durability of the PP5-Xtreme (Figure 26).

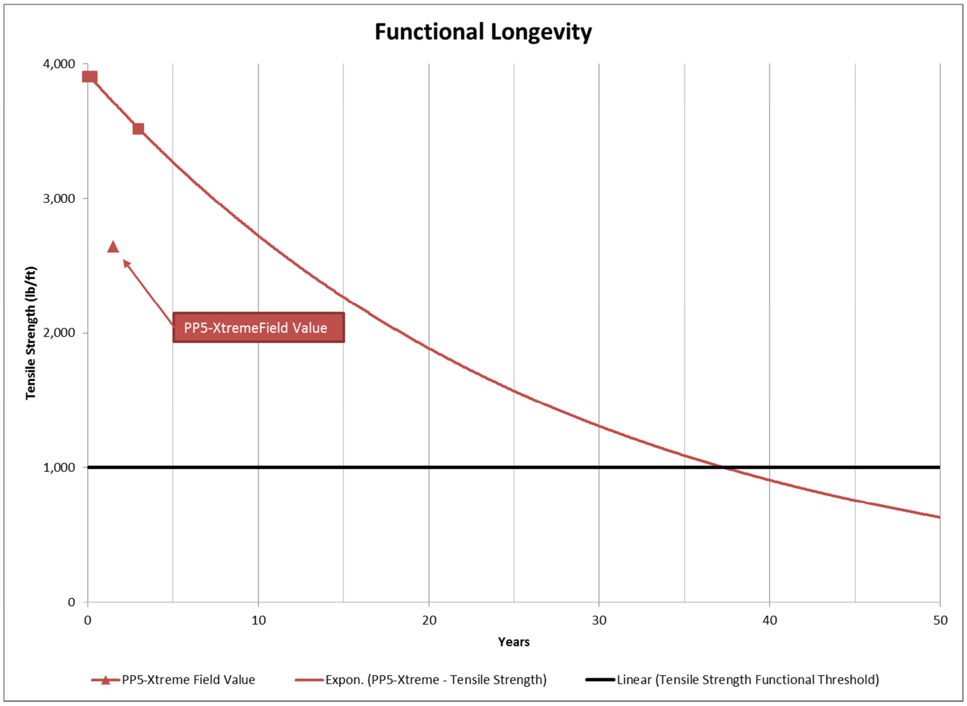

Figure 26 PP5-Xtreme Functional Longevity with Field Value

When compared to published UV testing, 66.0% strength retention corresponds to an exposure time of 32.0 months, giving a deceleration factor of 0.6. Applying this field correlated deceleration factor for PP5-Xtreme along with the previously established modes of degradation the functional longevity graph is generated using the laboratory test data and field values and is shown in Figure 27.

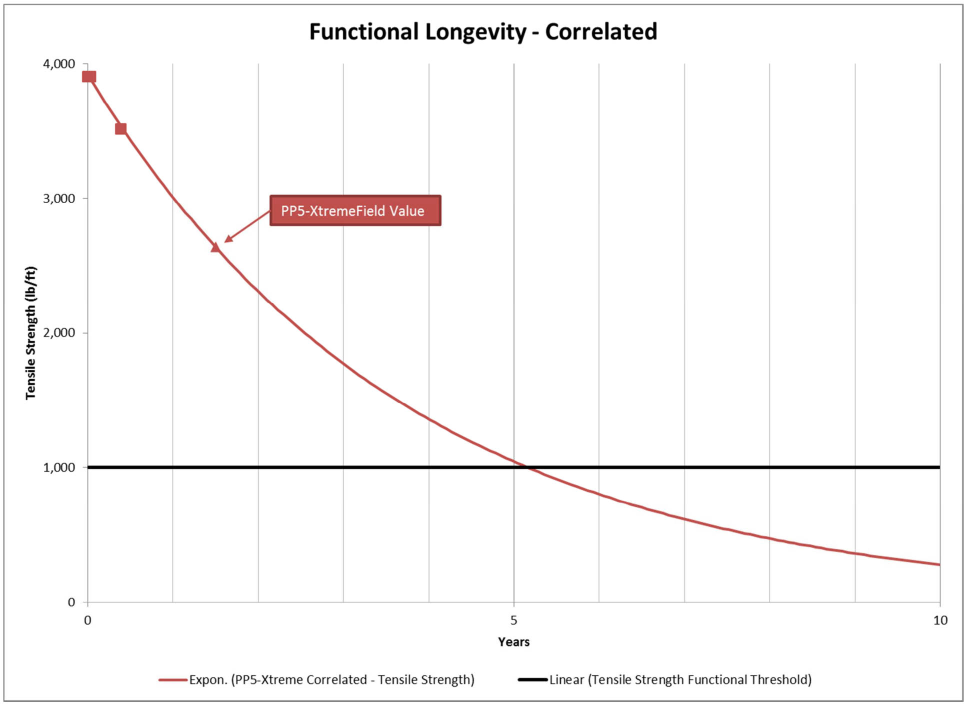

Figure 27 Correlated Functional Longevity of PP5-Xtreme

The inclusion of the field correlated deceleration factor decreases the functional longevity of PP5-Xtreme from <35 years to <5 years based on tensile strength.

CHAPTER VI

CONCLUSION

The analysis presented herein evaluates the existing published data with an understanding of environmental factors and material degradation to consistently quantify the material degradation over time for specific GRECPs available in the North American marketplace. It was found when using the assumed environmental conditions and acceleration factors, that the functional longevity of the stitch-bonded and heat-bonded GRECPs, regardless of material type was less than 5 years. The functional longevity for the woven GRECPs was also found to be significantly higher than the stitch-bonded and heat-bonded GRECPs, with woven TRMs showing up to 25 years of functional longevity and woven HPTRMs showing up to 40 years of functional longevity. The field evaluations showed that true proven performance is shown over the GRECPs functional longevity in real world applications. While the two GRECPs evaluated showed similar published properties, the field evaluation of the PP5-Xtreme HPTRM revealed a functional longevity of less than 5 years, while the field evaluation of the Pyramat HPTRM exhibited a functional longevity of over 50 years.

When compared to their respective functional thresholds, the changes in durability and coverage over time were effectively quantified to evaluate the functional longevity for each GRECP. With the functional longevity established through a consistent process for each material, the GRECPs can be more accurately compared. Adequate coverage and durability is imperative for the performance of GRECPs. With a better understanding of a GRECP's coverage and durability and the factors effecting the GRECP's functional longevity, project specific design requirements can be further refined resulting in more appropriate selection of GRECPs and greater project success rates.

CHAPTER VII

RECOMMENDATIONS

Field Correlations

In order to further understand the specific nature of UV degradation, tensile strength field correlations for additional GRECPs are needed. Tensile strength field correlations of Pyramat and PP5-Xtreme in different regions and for different lengths of exposure would provide additional validation while also providing insight when considering region-to-region correlations. Field correlation of coverage would provide additional validation to the importance of coverage as well as aid in understanding how coverage is truly affected by environmental conditions.

Modes of Degradation

Due to the complexity of polymers, additional research on other encountered modes of degradation would improve the accuracy of the functional longevity analysis. While biological degradation was generally addressed based on material category, additional data on product specific biological characteristics will help improve the accuracy of this mode of degradation. Additional testing on chemical degradation is also needed in order to fully apply this mode of degradation to the functional longevity analysis. While this functional longevity analysis applied the modes of degradation separately, additional research towards the interaction of the modes of degradation would help further refine the process and provide insight on if any particular mode of degradation accelerates or decelerates other modes of degradation.

Functional Threshold

As the degradation of each GRECP is evaluated against a functional threshold, additional research should also focus on determining different functional thresholds for tensile strength and coverage in various applications. The functional thresholds for tensile strength should be dependent upon the anticipated non-hydraulic stresses for each application as well as the level of risk of the project. The functional thresholds for coverage should be dependent upon the anticipated hydraulic stresses and vegetation density as well as the level of risk of the project.

Light Penetration

The light penetration test per ASTM D-6567 for GRECPs can give variable results depending on the construction and color of the GRECP. Testing has shown that when comparing materials with the same construction, GRECPs having a lighter color will result in a higher value for light penetration than a GRECP with a darker color. Because of the variation of GRECP construction types, a versatile test is needed to provide a consistent comparison. While light penetration points toward the percent open area or percent coverage of the GRECP, a further refined test procedure with less product-to-product variability would improve the data and understanding of a GRECP's coverage.

REFERENCES

ASTM. (2014). *ASTM D-4355-14: Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus.* West Conshohocken, PA: American Society for Testing and Materials.

ASTM. (2014). *ASTM D-4439-14: Standard Terminology for Geosynthetics.* West Conshohocken, PA: American Society for Testing and Materials.

ASTM. (2014). *ASTM D-6567-14: Standard Test Method for Measuring the Light Penetration of a Turf Reinforcement Mat (TRM).* West Conshohocken, PA: American Society for Testing and Materials.

ASTM. (2014). *ASTM D-6818-14: Standard Test Method for Ultimate Tensile Properties of Rolled Erosion Control Products.* West Conshohocken, PA: American Society for Testing and Materials.

Durham, A. (2012). *TB-Functional Longevity of Turf Reinforcement Mats.* Propex Operating Company, LLC.

Durham, A. (2014). *Hydraulic Performance of TRMs as a Function of Light Penetration (ASTM D6567) and Woven Fiber Cross-Sectional Shape.* Propex Operating Company, LLC.

GEOfabrics. (2011). *The Durability of Geotextiles.* GEOfabrics Limited.

Hsuan, Y. G., Schroeder, H. F., Rowe, K., Müller, W., Greenwood, J., Cazzuffi, D., et al. (2014). *Long-Term Performance and Lifetime Prediction of Geosynthetics.* EuroGeo4 Keynote Paper.

Hughes, S., & Thornton, C. (2014). *Evaluation of HPTRM Performance as a Function of Mesh Openings and Grass Root Parameters.* Colorado State University – Engineering Research Center.

Khanna, S. (2005). *Aging Effects of Environmental Factors on Rolled Erosion Control Products.* Texas A&M University.

Koerner, R. M., Hsuan, Y. G., & Koerner, G. R. (2011). *GRI White Paper #6 - Geomembrane Lifetime Prediction: Unexposed and Exposed Conditions.* Geosynthetic Institute.

Miller, S. J., Fischenich, J. C., & Thornton, C. I. (2012). *Stability thresholds and performance standards for flexible lining materials in channel and slope restoration applications.* EBA Technical Notes Collection. Vicksburg, MS: ERDC TN-EMRRP- EBA-13.

Propex. (2006). *EB-405 The Durability of Polypropylene Geotextiles for Waste Containment Applications.* Propex Operating Company, LLC.

Propex. (2014). *EB-532 Ultraviolet Light Degradation of Geotextiles.* Propex Operating Company, LLC.

Propex. (2014). *EB-603 Understanding Typical Values, Minimum Average Roll Values (MARVs), and Minimum Values (MVs).* Propex Operating Company, LLC.

TenCate. (2010). *Technical Note - UV Durability of TenCate Geosynthetics.* TenCate Geosynthetics North America.

APPENDIX A

GRECP DATA SHEETS

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RECYCLEX® TRM PRODUCT DATA SHEET

DESCRIPTION

Recyclex TRM, permanent non-degradable Turf Reinforcement Mat, consists of 100% post-consumer recycled polyester (green or brown bottles) with 80% five-inch fibers or greater fiber length. It is of consistent thickness with fibers evenly distributed throughout the entire area of the TRM. The top of each TRM is covered with extra heavy duty polypropylene net and the bottom of each is covered with heavy duty polypropylene net. Fibers are tightly crimped and curled to allow fiber interlock, and to retain 95% memory of the original shape after loading by hydraulic events. Fibers have a specific gravity greater than 1.0; therefore, the blanket will not float during hydraulic events. Recyclex TRM meets Federal Government Executive Order initiatives for use of products made from, or incorporating, recycled materials. TRM shall be Manufactured in the U.S.A. and the fibers shall be made from 100% recycled post-consumer goods.

Recyclex has a design soil loss ratio (event-based RUSLE C factor) of .022 and is typically suitable for slopes up to 0.5:1. Vegetated Recyclex is rated for channel flows up to 17.0+ ft/s (5.2+ m/s) and 10.0+ lb/ft^2 (480+ Pa) shear stress.

PHYSICAL PROPERTIES

Recyclex measurements at time of manufacturing:

Width		8.0 ft (2.4 m)	16 ft (4.9 m)
Length		90.0 ft (27.4 m)	90.0 ft (27.4 m)
Area		80.0 yd^2 (66.9 m^2)	160.0 yd^2 (133.8 m^2)
Weight		50.0 lb (22.7 kg)	100.0 lb (45.4 kg)
Fiber Length (80% min.)		≥5.0 in (≥12.7 cm)	≥5.0 in (≥12.7 cm)
Mass per Unit Area (± 10%)		0.625 lb/yd^2 (0.34 kg/m^2)	0.625 lb/yd^2 (0.34 kg/m^2)
Net Openings	Polypropylene Top	0.75 in x 1.0 in (19.1 mm x 25.4 mm)	0.75 in x 1.0 in (19.1 mm x 25.4 mm)
	Polypropylene Bottom	0.75 in x 0.75 in (19.1 mm x 19.1 mm)	0.75 in x 0.75 in (19.1 mm x 19.1 mm)

TYPICAL INDEX VALUES*

Index Property	Test Method	Value
Thickness	ASTM D 6525	0.371 in (9.4 mm)
Light Penetration	ECTC Procedure	55%
Resiliency	ASTM D 6524	85%
Mass per Unit Area	ASTM D 6566	0.63 lb/yd^2 (342 g/m^2)
MD-Tensile Strength Max.	ASTM D 6818	387.6 lb/ft (5.7 kN/m)
TD-Tensile Strength Max.	ASTM D 6818	340.8 lb/ft (5.0 kN/m)
MD-Elongation	ASTM D 6818	21.2%
TD-Elongation	ASTM D 6818	20.3%
Swell	ECTC Procedure	26%
Water Absorption	ASTM D 1117/ECTC	20%
Specific Gravity	ASTM D 792	1.28
UV Stability	ASTM D 4355 (1,000 hr)	90% minimum
Porosity	Calculated	97.6%
Bench-Scale Rain Splash	ECTC Method 2	SLR = 6.17 @ 2 in/hr
Bench-Scale Rain Splash	ECTC Method 2	SLR = 5.90 @ 4 in/hr
Bench-Scale Rain Splash	ECTC Method 2	SLR = 5.63 @ 6 in/hr
Bench-Scale Shear	ECTC Method 3	2.84 lb/ft^2 @ 0.5" soil loss
Germination Improvement	ECTC Method 4	525.6%

* SLR is the Soil Loss Ratio, as reported by NTPEP/AASHTO. Bench-scale index values should not be used for design purposes.

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W0712R1112

Figure 28 Recyclex TRM PDS

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Material and Performance Specification

ECC-3™ Coconut Turf Reinforcement Mat

Description:

The ECC-3™ is made with uniformly distributed 100% coconut fiber and three polypropylene nets securely sewn together with UV stabilized thread. The tightly compressed blankets are wrapped and include a product label, code and installation guide. The blankets are palletized for easy transportation.
The ECC-3™ is a permanent turf reinforcement mat and is suitable for 1:1 slopes and high-flow channels.

Matrix:	1	2
	100% Coconut	

Netting:	Type	Net Color
Top:	Medium weight 8# PMSF UV Stabilized Polypropylene	Black
Middle:	Heavyweight 24# PMSF UV Stabilized Polypropylene	
Bottom:	Medium weight 8# PMSF UV Stabilized Polypropylene	

Net Opening:	Top	Middle	Bottom
	0.5" x 0.5"	0.4" x 0.5"	0.5" x 0.5"

Thread:	Type	Color
	UV Stabilized Thread	

Roll Sizes:	Standard		"A" Size		Mega	
Width:	7.5 ft	2.3 m	3.75 ft	1.1 m	15 ft	4.6 m
Length:	120 ft	36.6 m	240 ft	73.2 m	120 ft	36.6 m
Weight ±10%:	92 lbs	41.7 kg	92 lbs	41.7 kg	184 lbs	83.5 kg
Area:	100 yd^2	83.6 m^2	100 yd^2	83.6 m^2	200 yd^2	167.2 m^2
#/Pallet:	9		4		9	

Index Value Properties*:

Property	Test Method	Typical			
Mass/Unit Area	ASTM D6566	13.25	oz/yd^2	449.2	g/m2
Thickness	ASTM D6525	0.34	in	8.64	mm
Tensile Strength-MD	ASTM D6818	802	lb/ft	11.70	kN/m
Elongation-MD	ASTM D6818	25	%		
Tensile Strength-TD	ASTM D6818	790	lb/ft	11.53	kN/m
Elongation-TD	ASTM D6818	15.7	%		
Light Penetration	ASTM D6567	14	%		
Density / Specific Gravity	ASTM D792	0.888	g/cm^3		
Water Absorption	ASTM D1117	113	%		
Resiliency	ASTM D6524	N/A	%		
UV Resistance	ASTM D4355	98	%	1000	hours

*May differ depending upon raw material variations

Bench-Scale Testing* (NTPEP***):

Test Method	Parameters	Results
ECTC Method 2 Rainfall	50mm (2in) / hr-30 min	SLR**=7.70
	100mm (4in) / hr-30 min	SLR**=10.43
	150mm (6in) / hr-30 min	SLR**=14.18
ECTC Method 3 Shear Resistance	Shear at .50 in soil loss	3.13 lb/ft^2
ECTC Method 4 Germination	Top soil; Fescue; 21 day incubation	364 %

*Bench scale tests should not be used for design purposes.
**Soil Loss Ratio=Soil Loss Bare Soil/Soil Loss with RECP=1/C-Factor

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Slope Performance Design Values*:

Property	Test Method		Value
C-Factors	ASTM D6459		0.00
Slope Length (L)	**≤ 3:1**	**3:1-2:1**	**≥ 2:1**
< 50 ft (15 m)	0.001	0.007	0.047
50 ft – 100 ft	0.008	0.015	0.069
>100 ft (30 m)	0.027	0.050	0.089

*Large-Scale Results obtained by 3rd Party GAI Accredited Independent Laboratory

Channel Performance Design Values*:

Property	Test Method	Value			
Unvegetated Shear Stress	ASTM D 6460	3.20	lbs/ft^2	153.22	Pa
Unvegetated Velocity	ASTM D 6460	11.5	ft/s	3.51	m/s
Vegetated Shear Stress	ASTM D 6460	12.0	lbs/ft^2	574.56	Pa
Vegetated Velocity	ASTM D 6460	25.0	ft/s	7.62	m/s
Manning's N (Value Represents a Range)		0.024			

*Large-Scale Results obtained by 3rd Party GAI Accredited Independent Laboratory

The values presented are for guidance purposes and do not constitute the practice of engineering. East Coast Erosion Blankets LLC (ECEB) ascertains that at the time of manufacture, all information presented herein is accurate and reliable and falls within the ECEB manufacturing product specification variances. If the product does not meet the stated values and ECEB is notified in writing prior to installation, the product will be replaced at no cost to the purchaser. ECEB will not be held liable for any type of damage or losses, directly, or indirectly for failure of this product. Current revision supersedes all previous versions for this product.

Revised 01/01/2014

Figure 29 ECC-3 PDS

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Material and Performance Specification

ECP-2™ Polypropylene Turf Reinforcement Mat

Description:

The ECP-2™ is made with uniformly distributed 100% green polypropylene fiber and two medium weight polypropylene nets securely sewn together with UV stabilized thread. The tightly compressed blankets are wrapped and include a product label, code and installation guide. The blankets are palletized for easy transportation. The ECP-2™ is a permanent turf reinforcement mat and is suitable for 1:1 slopes and high-flow channels. The ECP-2™ meets Type 5.A, 5.B, and 5.C specification requirements established by the Erosion Control Technology Council (ECTC) and Federal Highway Administration's (FHWA) FP-03 Section 713.18.

Matrix:	1	2
	Green or Tan Polypropylene Fiber	

Netting:	Type	Net Color
Top:	Medium weight 5# PMSF UV Stabilized Polypropylene	Black
Middle:	None	
Bottom:	Medium weight 5# PMSF UV Stabilized Polypropylene	

Net Opening:	Top	Middle	Bottom
	0.5" x 0.5"		0.5" x 0.5"

Thread:	Type	Color
	UV Stabilized Thread	Black

Roll Sizes:	Standard		"A" Size		Mega	
Width:	7.5 ft	2.3 m	3.75 ft	1.1 m	15 ft	4.6 m
Length:	120 ft	36.6 m	240 ft	73.2 m	120 ft	36.6 m
Weight ±10%:	75 lbs	34.0 kg	75 lbs	34.0 kg	150 lbs	68.0 kg
Area:	100 yd^2	83.6 m^2	100 yd^2	83.6 m^2	200 yd^2	167.2 m^2
#/Pallet:	9		6		9	

Index Value Properties*:

Property	Test Method	Typical	
Mass/Unit Area	ASTM D6566	12.00 oz/yd^2	406.9 g/m2
Thickness	ASTM D6525	0.40 in	10.16 mm
Tensile Strength-MD	ASTM D6818	400 lb/ft	5.84 kN/m
Elongation-MD	ASTM D6818	31 %	
Tensile Strength-TD	ASTM D6818	400 lb/ft	5.84 kN/m
Elongation-TD	ASTM D6818	19.0 %	
Light Penetration	ASTM D6567	18 %	
Density / Specific Gravity	ASTM D792	0.915 g/cm^3	
Water Absorption	ASTM D1117	0 %	
Resiliency	ASTM D6524	80 %	
UV Resistance	ASTM D4355	82 %	1000 hours

*May differ depending upon raw material variations

Bench-Scale Testing* (NTPEP*):**

Test Method	Parameters	Results
ECTC Method 2 Rainfall	50mm (2in) / hr-30 min	SLR**=5.53
	100mm (4in) / hr-30 min	SLR**=5.38
	150mm (6in) / hr-30 min	SLR**=5.22
ECTC Method 3 Shear Resistance	Shear at .50 in soil loss	2.72 lb/ft^2
ECTC Method 4 Germination	Top soil; Fescue; 21 day incubation	469 %

*Bench scale tests should not be used for design purposes.

**Soil Loss Ratio=Soil Loss Bare Soil/Soil Loss with RECP=1/C-Factor

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Slope Performance Design Values*:

Property	Test Method		Value
C-Factors	ASTM D6459		0.01
Slope Length (L)	**≤ 3:1**	**3:1-2:1**	**≥ 2:1**
< 50 ft (15 m)	0.012	0.025	0.092
50 ft – 100 ft	0.036	0.065	0.115
>100 ft (30 m)	0.080	0.108	0.145

*Large-Scale Results obtained by 3rd Party GAI Accredited Independent Laboratory

Channel Performance Design Values*:

Property	Test Method	Value			
Unvegetated Shear Stress	ASTM D 6460	2.60	lbs/ft^2	124.49	Pa
Unvegetated Velocity	ASTM D 6460	10.0	ft/s	3.05	m/s
Vegetated Shear Stress	ASTM D 6460	12.0	lbs/ft^2	574.56	Pa
Vegetated Velocity	ASTM D 6460	20.0	ft/s	6.10	m/s
Manning's N (Value Represents a Range)		0.028			

*Large-Scale Results obtained by 3rd Party GAI Accredited Independent Laboratory

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Figure 30 ECP-2 PDS

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Material and Performance Specification

ECSC-3™ Straw/Coconut Turf Reinforcement Mat

Description:

The ECSC-3™ is made with uniformly distributed 70% agricultural straw, 30% coconut fiber and three polypropylene nets securely sewn together with UV stabilized thread. The tightly compressed blankets are wrapped and include a product label, code and installation guide. The blankets are palletized for easy transportation. The ECSC-3™ is a permanent turf reinforcement mat and is suitable for 1:1 slopes and high-flow channels.

Matrix:	1	2
	70% Straw	30% Coconut

Netting:	Type	Net Color
Top:	Medium weight 5# PMSF UV Stabilized Polypropylene	Black
Middle:	Heavyweight 24# PMSF UV Stabilized Polypropylene	
Bottom:	Medium weight 5# PMSF UV Stabilized Polypropylene	

Net Opening:	Top	Middle	Bottom
	0.5" x 0.5"	0.4" x 0.5"	0.5" x 0.5"

Thread:	Type	Color
	UV Stabilized Thread	Black

Roll Sizes:	Standard		"A" Size		Mega	
Width:	7.5 ft	2.3 m	3.75 ft	1.1 m	15 ft	4.6 m
Length:	120 ft	36.6 m	240 ft	73.2 m	120 ft	36.6 m
Weight +10%:	92 lbs	41.7 kg	92 lbs	41.7 kg	184 lbs	83.5 kg
Area:	100 yd^2	83.6 m^2	100 yd^2	83.6 m^2	200 yd^2	167.2 m^2
#/Pallet:	9		4		9	

Index Value Properties*:

Property	Test Method	Typical	
Mass/Unit Area	ASTM D6566	14.00 oz/yd^2	474.7 g/m2
Thickness	ASTM D6525	0.39 in	9.91 mm
Tensile Strength-MD	ASTM D6818	756 lb/ft	11.03 kN/m
Elongation-MD	ASTM D6818	21 %	
Tensile Strength-TD	ASTM D6818	632 lb/ft	9.22 kN/m
Elongation-TD	ASTM D6818	20.8 %	
Light Penetration	ASTM D6567	7 %	
Density / Specific Gravity	ASTM D792	0.919 g/cm^3	
Water Absorption	ASTM D1117	259 %	
Resiliency	ASTM D6524	N/A %	
UV Resistance	ASTM D4355	80 %	500 hours

*May differ depending upon raw material variations

Bench-Scale Testing* (NTPEP*):**

Test Method	Parameters	Results
ECTC Method 2 Rainfall	50mm (2in) / hr-30 min	SLR**=18.16
	100mm (4in) / hr-30 min	SLR**=17.83
	150mm (6in) / hr-30 min	SLR**=17.50
ECTC Method 3 Shear Resistance	Shear at .50 in soil loss	3.40 lb/ft^2
ECTC Method 4 Germination	Top soil; Fescue; 21 day incubation	497 %

*Bench scale tests should not be used for design purposes.

**Soil Loss Ratio=Soil Loss Bare Soil/Soil Loss with RECP=1/C-Factor

***The preceding test data excerpts were reproduced with the permission of AASHTO, however, this does not constitute endorsement or approval of the product, material or device by AASHTO

Slope Performance Design Values*:

Property	Test Method		Value
C-Factors	ASTM D6459		0.01
Slope Length (L)	**≤ 3:1**	**3:1-2:1**	**≥ 2:1**
< 50 ft (15 m)	0.006	0.012	0.072
50 ft – 100 ft	0.026	0.042	0.086
>100 ft (30 m)	0.062	0.082	0.132

*Large-Scale Results obtained by 3rd Party GAI Accredited Independent Laboratory

Channel Performance Design Values*:

Property	Test Method	Value			
Unvegetated Shear Stress	ASTM D 6460	3.00	lbs/ft^2	143.64	Pa
Unvegetated Velocity	ASTM D 6460	11.0	ft/s	3.35	m/s
Vegetated Shear Stress	ASTM D 6460	10.0	lbs/ft^2	478.80	Pa
Vegetated Velocity	ASTM D 6460	20.0	ft/s	6.10	m/s
Manning's N (Value Represents a Range)		0.024			

*Large-Scale Results obtained by 3rd Party GAI Accredited Independent Laboratory

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Figure 31 ECSC-3 PDS

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Material and Performance Specification

T-RECS®

Turf Reinforcement Erosion Control Solution®

The high-performance T-RECS® Turf Reinforcement Mat is a permanent three dimensional, woven polypropylene geotextile designed for steep slopes up to 0.5:1 and is an ideal non-hard armoring solution for high velocity channels.

T-RECs® is manufactured with a patented process of cross directional monofilament fibers woven into multiple dimensions featuring the T-RECS® Technology with dome characteristics. This unique process and feature aids in the performance of the product and gives additional support to the vegetation. The product provides reinforcing capabilities and interlocking root system, while assisting the vegetation establishment. Product can be either surface applied or soiled filled to maximize performance.

The T-RECS® meets Type 5.A, 5.B, and 5.C specification requirements established by the Erosion Control Technology Council (ECTC) and Federal Highway Administration's (FHWA) FP-03 Section 713.18.

INDEX VALUE PROPERTIES

PROPERTY	TEST METHOD[2]	ENGLISH	METRIC
Mass Per Unit Area[3]	ASTM D 6566	8.50 oz/yd^2	288.2 g/m^2
Thickness	ASTM D 6525	.45 inch	11.4 mm
Tensile Strength-MD[3]	ASTM D 6818	3000	44 kN/m
Elongation – MD	ASTM D 6818	41%	
Tensile Strength-TD[3]	ASTM D 6818	3000	44 kN/m
Elongation-TD	ASTM D 6818	17%	
Light Penetration	ASTM D 6567	34%	
Germination/Seedling Emergence	ECTC Method 4	636% Improvement	
UV Resistance (6,000 hours)	ASTM D4355	91%	
Resiliency	ASTM D 6524	70%	
Flexibility	ASTM D 6575	0.3 in/lb	1.7 cm/kg
Color	Observed	Green/Blue or Tan/Blue	
Roll Size	Measured	12.0 ft x 70.0 ft	1.8 m x 27.4 m

PERFORMANCE DESIGN VALUES

PROPERTY	TEST METHOD[1]	ENGLISH[2]	METRIC[2]
Vegetated Shear Stress	ASTM D 6460	15 lb/ft^2	718 Pa
Vegetated Velocity	ASTM D 6460	25 ft/sec	7.6 m/sec
Manning's N	ASTM D 6460	0.028	

1 Modified Test Method
2 Results obtained by 3rd Party GAI Accredited Independent Laboratory
3 Minimum Average Roll Value

Proud Member of:

ECTC Directing Member · IECA Emerald Member · ASTM International

MADE IN USA

The values presented are for guidance purposes and do not constitute the practice of engineering. East Coast Erosion Blankets LLC (ECEB) ascertains that at the time of manufacture, all information presented herein is accurate and reliable and falls within the ECEB manufacturing product specification variances. If the product does not meet the stated values and ECEB is notified in writing prior to installation, the product will be replaced at no cost to the purchaser. ECEB will not be held liable for any type of damage or losses, directly, or indirectly for fail of this product. Current revision supersedes all previous versions for this product.

Revised 01012014

Figure 32 T-RECS PDS

NORTH AMERICAN GREEN®

A tensar. Company

Material and Performance Specification Sheet

North American Green
14649 Highway 41 North
Evansville, IN 47725
800-772-2040
FAX: 812-867-0247
www.nagreen.com

C350 Turf Reinforcement Mat

The composite turf reinforcement mat (C-TRM) shall be a machine-produced mat of 100% coconut fiber matrix incorporated into a permanent three-dimensional turf reinforcement matting. The matrix shall be evenly distributed across the entire width of the matting and stitch bonded between a super heavy duty UV stabilized nettings with 0.50 x 0.50 inch (1.27 x 1.27 cm) openings, an ultra heavy UV stabilized, dramatically corrugated (crimped) intermediate netting with 0.5 x 0.5 inch (1.27 x 1.27 cm) openings, and covered by an super heavy duty UV stabilized nettings with 0.50 x 0.50 inch (1.27 x 1.27 cm) openings. The middle corrugated netting shall form prominent closely spaced ridges across the entire width of the mat. The three nettings shall be stitched together on 1.50 inch (3.81cm) centers with UV stabilized polypropylene thread to form a permanent three-dimensional turf reinforcement matting.

The C350 shall meet requirements established by the Erosion Control Technology Council (ECTC) Specification and the US Department of Transportation, Federal Highway Administration's (FHWA) *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-03 Section 713.18 as a Type 5A, B, and C Permanent Turf Reinforcement Mat.*

Installation staple patterns shall be clearly marked on the turf reinforcement matting with environmentally safe paint. All mats shall be manufactured with a colored thread stitched along both outer edges (approximately 2-5 inches [5-12.5 cm] from the edge) as an overlap guide for adjacent mats.

Material Content		
Matrix	100% Coconut fibers	0.50 lbs/yd² (0.27 kg/m²)
Nettings	Top and Bottom, UV stabilized Polypropylene	8 lb/1000 ft² (3.91 kg/100 m²)
	Middle, corrugated UV stabilized Polypropylene	24 lb/1000 ft² (11.7 kg/100 m²)
Thread	Polypropylene, UV stabilized	

C350 is available in the following roll sizes:

Width	6.5 ft (2.0 m)
Length	55.5 ft (16.9 m)
Weight ± 10%	37 lbs (16.8 kg)
Area	40.0 yd² (33.4 m²)

Index Value Properties:

Property	**Test Method**	**Typical**	**Net Only**
Thickness	ASTM D6525	0.67 in (17.0 mm)	0.51 in
Resiliency	ASTM 6524	90%	---
Density	ASTM D792	0.53 oz/in³	---
Mass/Unit Area	ASTM 6566	12.57 oz/yd² (426 g/m²)	---
Porosity	ECTC Guidelines	99%	---
Stiffness	ASTM D1388	3.83 oz-in	---
Light Penetration	ECTC Guidelines	9.0%	---
UV Stability	ASTM D4355/ 1000 hr	86%	86%
Tensile Strength MD	ASTM D6818	625 lbs/ft (9.12 kN/m)	698 lbs/ft
Elongation MD	ASTM D6818	22%	30%
Tensile Strength TD	ASTM D6818	768 lbs/ft (11.21 kN/m)	710 lbs/ft
Elongation TD	ASTM D6818	15%	20%

Bench Scale Testing* (NTPEP):

Test Method	**Parameters**	**Results**
ECTC Method 2 Rainfall	50 mm (2 in)/hr for 30 min	SLR** = 18.32
	100mm (4 in)/hr for 30 min	SLR** = 19.65
	150 mm (6 in)/hr for 30 min	SLR** = 20.48
ECTC Method 3 Shear Resistance	**Shear at 0.50 inch soil loss**	**7.5 lbs/ft²**
ECTC Method 4 Germination	Top Soil, Fescue, 21 day incubation	243% improvement of biomass

* Bench Scale tests should not be used for design purposes

** Soil Loss Ratio = Soil loss with Bare Soil/Soil Loss with RECP (soil loss is based on regression analysis)

Updated 3/09

Performance Design Values:

Maximum Permissible Shear Stress		
	Short Duration	Long Duration
Phase 1 Unvegetated	3.2 lbs/ft² (153 Pa)	3.0 lbs/ft² (144 Pa)
Phase 2 Partially Veg.	10.0 lbs/ft² (480 Pa)	10.0 lbs/ft² (480 Pa)
Phase 3 Fully Veg.	12.0 lbs/ft² (576 Pa)	10.0 lbs/ft² (480 Pa)
Velocity Unveg	10.5 ft/s (3.2 m/s)	
Velocity Veg.	20 ft/s (6.0 m/s)	

Slope Design Data: C Factors			
	Slope Gradients (S)		
Slope Length (L)	≤ 3:1	3:1 – 2:1	≥ 2:1
≤ 20 ft (6 m)	0.0005	0.015	0.043
20-50 ft	0.018	0.031	0.050
≥ 50 ft (15.2 m)	0.035	0.047	0.057

Roughness Coefficients- Unveg.	
Flow Depth	Manning's n
≤ 0.50 ft (0.15 m)	0.041
0.50 – 2.0 ft	0.040 – 0.013
≥ 2.0 ft (0.60 m)	0.012

Product Participant of: QDOR PERFORMANCE VERIFIED

Figure 33 C350 PDS

NORTH AMERICAN GREEN®

A tensar Company

Material and Performance Specification Sheet

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800-772-2040
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SC250 Turf Reinforcement Mat

The composite turf reinforcement mat (C-TRM) shall be a machine-produced mat of 70% straw and 30% coconut fiber matrix incorporated into a permanent three-dimensional turf reinforcement matting. The matrix shall be evenly distributed across the entire width of the matting and stitch bonded between a heavy duty UV stabilized netting with 0.50 x 0.50 inch (1.27 x 1.27 cm) openings, an ultra heavy UV stabilized, dramatically corrugated (crimped) intermediate netting with 0.5 x 0.5 inch (1.27 x 1.27 cm) openings, and covered by an heavy duty UV stabilized nettings with 0.50 x 0.50 inch (1.27 x 1.27 cm) openings. The middle corrugated netting shall form prominent closely spaced ridges across the entire width of the mat. The three nettings shall be stitched together on 1.50 inch (3.81cm) centers with UV stabilized polypropylene thread to form a permanent three-dimensional turf reinforcement matting.

The SC250 shall meet requirements established by the Erosion Control Technology Council (ECTC) Specification and the US Department of Transportation, Federal Highway Administration's (FHWA) *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, FP-03 Section 713.18 as a type 5A, B, and C Permanent Turf Reinforcement Mat.*

Installation staple patterns shall be clearly marked on the turf reinforcement matting with environmentally safe paint. All mats shall be manufactured with a colored thread stitched along both outer edges (approximately 2-5 inches [5-12.5 cm] from the edge) as an overlap guide for adjacent mats.

Material Content		
Matrix	70% Straw / 30% Coconut fibers	0.35 lbs/yd² (0.19 kg/m²) / 0.15 lbs/yd² (0.08 kg/m²)
Nettings	Top and Bottom, UV stabilized Polypropylene	5 lb/1000 ft² (2.44 kg/100 m²)
	Middle, corrugated UV stabilized Polypropylene	24 lb/1000 ft² (11.7 kg/100 m²)
Thread	Polypropylene, UV stabilized	

SC250 is available in the following roll sizes:

Width	6.5 ft (2.0 m)
Length	55.5 ft (16.9 m)
Weight ± 10%	34 lbs (15.42 kg)
Area	40.0 yd² (33.4 m²)

Index Value Properties:

Property	**Test Method**	**Typical**	**Net Only**
Thickness	ASTM D6525	0.72 in (18.3 mm)	0.48 in
Resiliency	ASTM 6524	95.2%	---
Density	ASTM D792	0.53 oz/in³	---
Mass/Unit Area	ASTM 6566	17.88 oz/yd² (606 g/m²)	---
Porosity	ECTC Guidelines	99%	---
Stiffness	ASTM D1388	222.65 oz-in	---
Light Penetration	ECTC Guidelines	8.9%	---
UV Stability	ASTM D4355/ 1000 hr	100%	100%
Tensile Strength MD	ASTM D6818	620 lbs/ft (9.05 kN/m)	655 lbs/ft
Elongation MD	ASTM D6818	35%	25%
Tensile Strength TD	ASTM D6818	737 lbs/ft (10.75 kN/m)	666 lbs/ft
Elongation TD	ASTM D6818	16%	16%

Bench Scale Testing* (NTPEP):

Test Method	**Parameters**	**Results**
ECTC Method 2 Rainfall	50 mm (2 in)/hr for 30 min	SLR** = 18.25
	100mm (4 in)/hr for 30 min	SLR** = 20.97
	150 mm (6 in)/hr for 30 min	SLR** = 22.74
ECTC Method 3 Shear Resistance	**Shear at 0.50 inch soil loss**	**7.7 lbs/ft²**
ECTC Method 4 Germination	Top Soil, Fescue, 21 day incubation	523% improvement of biomass

* Bench Scale tests should not be used for design purposes

** Soil Loss Ratio = Soil loss with Bare Soil/Soil Loss with RECP (soil loss is based on regression analysis)

Updated 3/09

Performance Design Values:

Maximum Permissible Shear Stress		
	Short Duration	Long Duration
Phase 1 Unvegetated	3.0 lbs/ft² (144 Pa)	2.5 lbs/ft² (120 Pa)
Phase 2 Partially Veg.	8.0 lbs/ft² (383 Pa)	8.0 lbs/ft² (383 Pa)
Phase 3 Fully Veg.	10.0 lbs/ft² (480 Pa)	8.0 lbs/ft² (383 Pa)
Velocity Unveg	9.5 ft/s (2.9 m/s)	
Velocity Veg.	15 ft/s (4.6 m/s)	

Slope Design Data: C Factors			
	Slope Gradients (S)		
Slope Length (L)	≤ 3:1	3:1 – 2:1	≥ 2:1
≤ 20 ft (6 m)	0.0010	0.0209	0.0507
20-50 ft	0.0081	0.0266	0.0574
≥ 50 ft (15.2 m)	0.0455	0.0555	0.081

Roughness Coefficients- Unveg.	
Flow Depth	Manning's n
≤ 0.50 ft (0.15 m)	0.040
0.50 – 2.0 ft	0.040 – 0.012
≥ 2.0 ft (0.60 m)	0.011

Product Participant of: QDOR PERFORMANCE VERIFIED

Figure 34 SC250 PDS

ROLLMAX™
ROLLED EROSION CONTROL

Specification Sheet – VMax® W3000™ High-Performance Turf Reinforcement Mat

DESCRIPTION

The VMax® W3000™ high performance turf reinforcement mat (HPTRM) is a machine-produced mat of 100% UV-stabilized high denier poly yarns woven into permanent, high strength three-dimensional turf reinforcement matting. The mat consists of a woven bottom layer integrally interlaced into a woven corrugated middle layer, with poly tendons on the top side spanning the entire machine direction. The mat is designed to provide sufficient thickness, optimum open area and three-dimensionality for effective erosion control and vegetation reinforcement against high flow induced shear forces. The mat has high tensile strength providing excellent damage resistance and increased bearing capacity of vegetated soils subject to heavy loads from maintenance equipment and other vehicular traffic. The corrugated structure provides a highly frictional surface to prevent sod slippage when sod is installed over the mat. When used as surface protection without sod overlay, the corrugated structure encapsulates the seed and soil in place while promoting self-soil infilling of the system.

Material Content		
Bottom	100% UV stable poly fiber weave	Black/Green
Corrugated Middle	100% UV stable poly fiber weave	Black/Green
Top	100% UV stable Poly Tendons	Green

Standard Roll Sizes	
Width	10 ft (3.05 m)
Length	90 ft (27.4 m)
Weight ± 10%	90 lbs (41.0 kg)
Area	100 sy (83.6 sm)

Index Property	Test Method	Typical
Thickness	ASTM D6525	0.40 in. (10.2 mm)
Resiliency	ASTM D6524	98%
Mass/Unit Area	ASTM 6566	14.7oz/sy (495 g/m2)
Tensile Strength - MD	ASTM D6818	3600 lbs/ft (52.6 kN/m)
Elongation - MD	ASTM D6818	35%*
Tensile Strength - TD	ASTM D6818	3800 lbs/ft (55.5 kN/m)
Elongation - TD	ASTM D6818	20%*
Light Penetration	ASTM D6567	12%
UV Stability	ASTM D4355	>80% @3000 hrs

** Measured on fabric prior to corrugation for true measurement of base fabric elongation*

Design Permissible Shear Stress*	
Vegetated Shear Stress	16 psf (766 Pa)
Vegetated Velocity	25 fps (7.6 m/s)

**Values extrapolated through ASTM D6460 testing*

ASTM D6460 Large Scale Channel	
Vegetated Shear Stress	>13.2 psf (632 Pa)
Vegetated Velocity	>24.5 fps (7.47 m/s)

Tensar.
NORTH AMERICAN GREEN®

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2500 Northwinds Parkway
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Alpharetta, GA 30009
800-TENSAR-1
tensarcorp.com

EC_RMX_MPDS_VW3000_5.13

Figure 35 W3000 PDS

Enkamat 7020

Turf Reinforcement Mat

Description

Enkamat® 7020 is a three-dimensional turf reinforcement mat (TRM) made of continuous monofilaments fused at their intersections. Ninety-five (95%) percent of the Enkamat is open and available for soil, mulch and root interaction, creating one of the most effective turf reinforcement mats available. Enkamat is manufactured from nylon to eliminate the buoyancy factor associated with submerged conditions and provides permanent TRM protection in vegetated channels and slopes.

Recommended Applications

- Permanent erosion control for vegetated channels and banks with expected shear stresses ≤ 17 psf.
- Permanent erosion control for moderate to steep slopes (≤0.5H:1V).
- Support and enhance performance of ecosystem plants.
- Substrate for hydraulically applied Flexible Growth Medium™ (FGM) and Bonded Fiber Matrix (BFM) to create the GreenArmor™ System.

Technical Data

Mechanical Properties	Test Method	Units	Roll Value	
			Typical	MARV
Tensile Strength	ASTM D6818	kN/m (lbs/ft)	3.5 (240)	2.6 (175)
Thickness	ASTM D6525	mm (in)	19 (0.75)	15.2 (0.6)
Mass/Unit Area	ASTM D6566	g/m^2 (oz/yd^2)	407 (12.0)	373 (11.0)
UV Stability	ASTM D7238 & D6818	%	80	
Resiliency	ASTM D6524	%	85	

Performance Properties	Test Method	Units	Typical Roll Value
Permissible Velocity			
30 minute, unvegetated	Flume test[1,2]	m/s (ft/s)	5.8 (19)
60 minute, vegetated	Flume test[1,2]	m/s (ft/s)	5.8 (19)
50 hour, vegetated	Flume test[1]	m/s (ft/s)	4.2 (14)
Permissible Shear Stress			
30 minute, unvegetated	Flume test[1,2]	kN/m^2 (lbs/ft^2)	0.28 (5.8)
60 minute, vegetated	Flume test[1,2]	kN/m^2 (lbs/ft^2)	0.81 (17.0)
50 hour, vegetated	Flume test[1]	kN/m^2 (lbs/ft^2)	0.38 (8.0)
Manning's n Range[3]	Flume test[1]	( )	0.025 — 0.045

1. Flume test performed at independent large scale laboratory — data and details available upon request. 2. Testing performed on GreenArmor™ System 3. Depending on vegetation type and height, use engineering field experience and examine a range of Manning's n values during design.

Packaging Data

Physical Properties	Units	Nominal Value	
Roll Dimensions *[width x length]*	m (ft)	0.99 x 84.4 (3.25 x 277)	1.93 x 27.5 (6.33 x 90)
Roll Area	m^2 (yd^2)	83.6 (100)	53 (63.3)
Estimated Roll Diameter	cm (in)	109 (43)	69 (27)
Estimated Roll Weight	kg (lb)	35 (77)	25 (54)
Color	Observed	Black	Black

Profile Products
750 Lake Cook Road, Ste. 440
Buffalo Grove, IL 60089
800-508-8681

www.profileproducts.com

04/2008 7020DS

Figure 36 Enkamat 7020 PDS

Enkamat R45

High Performance Turf Reinforcement Mat

Description

Enkamat R45 incorporates a unique manufacturing process that integrates a high tenacity polyester geogrid within thermally fused and entangled, three-dimensional nylon monofilaments to create a homogeneous, high performance turf reinforcement mat (HP-TRM). This unitized matrix develops high strength at very low elongation and when combined with Percussive Earth Driven Anchors (PDEAs) creates Anchor Armor™ Anchor Reinforced Vegetation Solution (ARVS). The high profile Enkamat R45 matrix also provides a high friction, interlocking "grip layer" under vegetation that can withstand light vehicle traffic and periodic mowing on slopes up to 3H:1V. Enkamat R45 is manufactured from nylon and polyester to eliminate buoyancy factors associated with submerged conditions and does not contain any loose nettings, fibers or stitching threads that could endanger wildlife, entangle mowing equipment or contaminate the environment.

Recommended Applications

- Permanent erosion control for vegetated channels, canals, banks, shorelines and levees with expected shear stresses ≤ 20 psf.
- Permanent erosion control for moderate to steep slopes (≤0.25H:1V).
- Substrate for hydraulically applied Flexible Growth Medium™ (FGM) and Bonded Fiber

Technical Data

Mechanical Properties	Test Method	Units	Typical Roll Value	
			MARV MD	MARV CD
Ultimate Tensile Strength	ASTM D6818	kN/m (lb/ft)	45 (3000)	45 (3000)
Tensile Strength @ 2%Strain	ASTM D6818	kN/m (lb/ft)	6.5 (450)	6.5 (450)
Thickness	ASTM D6525	mm (in)	19.0 (0.75)	
Mass/Unit Area (TRM+Grid)	ASTM D6566	g/m^2 (oz/yd^2)	544 (16)	
UV Stability at 2000 hours	ASTM D4355	%	80	
Resiliency	ASTM D6524	%	80	

Performance Properties	Test Method	Units	Value
Permissible Velocity			
30 minute, unvegetated	Flume test[1]	m/s (ft/s)	4.9 (16)
60 minute, vegetated	Flume test[1]	m/s (ft/s)	6.1 (30)
50 hour, vegetated	Flume test[1]	m/s (ft/s)	4.2 (14)
Permissible Shear Stress			
30 minute, unvegetated	Flume test[1]	kN/m^2 (lb/ft^2)	0.28 (5.8)
60 minute, vegetated	Flume test[1]	kN/m^2 (lb/ft^2)	0.96 (20.0)
50 hour, vegetated	Flume test[1]	kN/m^2 (lb/ft^2)	0.48 (10.0)
Manning's n Range[2]	Flume test[1]	( )	0.025 — 0.045

1. Flume test performed at independent large scale laboratory — data and details available upon request.
2. Depending on vegetation type and height, use engineering field experience and examine a range of Manning's n values during design.

Packaging

Physical Properties	Units	Nominal Value
Dimensions [width x length]	m (ft)	2.44 x 27.4 (8.0 x 90)
Roll Area	m^2 (yd^2)	66.9 (80.0)
Estimated Roll Diameter	m (in)	0.6 (24)
Estimated Roll Weight	kg (lb)	36 (80)
Color	Observed	Black

To the best of our knowledge, the information contained herein is accurate. However, we cannot assume any liability whatsoever for the accuracy or completeness thereof. Final determination of the suitability of any information or material for the use contemplated, of its manner of use and whether the suggested use infringes any patents is the sole responsibility of the user.

1/2012 R45DS

Figure 37 Enkamat R45 PDS

LANDLOK®
BY PROPEX

Product Data

LANDLOK® 300

LANDLOK® 300 turf reinforcement mat (TRM) is a three-dimensional, lofty, woven polypropylene geotextile that is available in green or tan which is specially designed for erosion control applications on steep slopes and vegetated waterways. The matrix is composed of polypropylene monofilament yarns featuring X3® technology woven into a uniform configuration of resilient pyramid-like projections. The material exhibits very high interlock and reinforcement capacity with both soil and root systems, demonstrates superior UV resistance, and enhances seedling emergence.

LANDLOK® 300 conforms to the property values listed below[1] and is manufactured at a Propex facility having achieved ISO 9001:2000 certification. Propex performs internal Manufacturing Quality Control (MQC) tests that have been accredited by the Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP).

PROPERTY	TEST METHOD	ENGLISH	METRIC
ORIGIN OF MATERIALS			
% U.S. Manufactured Inputs		100%	100%
% U.S. Manufactured		100%	100%
PHYSICAL			
Mass/Unit Area [2]	ASTM D-6566	7.5 oz/yd²	254 g/m²
Thickness [2]	ASTM D-6525	0.25 in	6.4 mm
Light Penetration (% Passing) [3]	ASTM D-6567	35%	35%
Color	Visual	Green or Tan	
MECHANICAL			
Tensile Strength [2]	ASTM D-6818	2000 x 1800 lbs/ft	29.2 x 26.3 kN/m
Elongation [2]	ASTM D-6818	50%	50%
Resiliency [2]	ASTM D-6524	70%	70%
Flexibility [4]	ASTM D-6575	0.195 in-lb	225,000 mg-cm
ENDURANCE			
UV Resistance % Retained at 3,000 hrs [4]	ASTM D-4355	90%	90%
PERFORMANCE			
Velocity (Vegetated) [4, 5]	Large Scale	20 ft/sec	6.1 m/sec
Shear Stress (Vegetated) [4, 5]	Large Scale	12 lb/ft²	575 Pa
Manning's n (Unvegetated) [4, 6]	Calculated	0.030	0.030
Seedling Emergence [4]	ASTM D-7322	255%	255%
ROLL SIZES		8.5 ft x 106 ft	2.6 m x 32.3 m

NOTES:

1. The property values listed above are effective 07/13/2015 and are subject to change without notice.
2. Minimum average roll values (MARV) are calculated as the typical minus two standard deviations. Statistically, it yields a 97.7% degree of confidence that any samples taken from quality assurance testing will exceed the value reported.
3. Maximum Average Roll Value (MaxARV), calculated as the typical plus two standard deviations. Statistically, it yields a 97.7% degree of confidence that any sample taken during quality assurance testing will meet to the value reported.
4. Typical Value.
5. Maximum permissible velocity and shear stress has been obtained through vegetated testing programs featuring specific soil types, vegetation classes, flow conditions, and failure criteria. These conditions may not be relevant to every project nor are they replicated by other manufacturers. Please contact Propex for further information.
6. Calculated as typical values from large-scale flexible channel lining test programs with a flow depth of 6 to 12 inches.

Propex™ Geotextile Systems

TESTED. PROVEN. TRUSTED

www.geotextile.com

Propex Operating Company, LLC · 1110 Market Street, Suite 300 · Chattanooga, TN 37422
ph 423 899 0444 · ph 800 621 1273 · fax 423 899 7619

Figure 38 Landlok 300 PDS

LANDLOK®
BY PROPEX

Product Data

LANDLOK® 450

LANDLOK® 450 turf reinforcement mat (TRM) features X3® technology that consists of a dense web of crimped, interlocking, multi-lobed polypropylene fibers positioned between two biaxially oriented nets and mechanically bound together by parallel stitching with polypropylene thread. The TRM is designed to accelerate seedling emergence, exhibit high resiliency, and possess strength and elongation properties to limit stretching in a saturated condition. Every component of LANDLOK® 450 is stabilized against chemical and ultraviolet degradation which are normally found in a natural soil environment. Furthermore, the TRM contains no biodegradable components.

LANDLOK® 450 conforms to the property values listed below[1] and is manufactured at a Propex facility having achieved ISO 9001:2000 certification. Propex performs internal Manufacturing Quality Control (MQC) tests that have been accredited by the Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP).

PROPERTY	TEST METHOD	ENGLISH	METRIC
ORIGIN OF MATERIALS			
% U.S. Manufactured Inputs		100%	100%
% U.S. Manufactured		100%	100%
PHYSICAL			
Mass/Unit Area [2]	ASTM D-6566	10.0 oz/yd²	339 g/m²
Thickness [2]	ASTM D-6525	0.40 in	10.2 mm
Light Penetration (% Passing) [2]	ASTM D-6567	20%	20%
Color	Visual	Green or Tan	
MECHANICAL			
Tensile Strength [2]	ASTM D-6818	400 x 300 lbs/ft	5.8 x 4.4 kN/m
Elongation [2]	ASTM D-6818	50%	50%
Resiliency [2]	ASTM D-6524	90%	90%
Flexibility [2]	ASTM D-6575	0.026 in-lb	30,000 mg-cm
ENDURANCE			
UV Resistance % Retained at 1,000 hrs [2]	ASTM D-4355	80%	80%
PERFORMANCE			
Velocity (Vegetated) [2, 3]	Large Scale	18 ft/sec	5.5 m/sec
Shear Stress (Vegetated) [2, 3]	Large Scale	10 lb/ft²	479 Pa
Manning's n (Unvegetated) [2, 4]	Calculated	0.025	0.025
Seedling Emergence [2]	ASTM D-7322	409%	409%
ROLL SIZES		6.5 ft x 138.5 ft	2.0 m x 42.2 m

NOTES:

1. The property values listed above are effective 07/13/2015 and are subject to change without notice.
2. Typical Value.
3. Maximum permissible velocity and shear stress has been obtained through vegetated testing programs featuring specific soil types, vegetation classes, flow conditions, and failure criteria. These conditions may not be relevant to every project nor are they replicated by other manufacturers. Please contact Propex for further information.
4. Calculated as typical values from large-scale flexible channel lining test programs with a flow depth of 6 to 12 inches.

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Figure 39 Landlok 450 PDS

PYRAMAT® BY PROPEX

Product Data

PYRAMAT®

PYRAMAT® high performance turf reinforcement mat (HPTRM) is a three-dimensional, lofty, woven polypropylene geotextile that is available in green or tan which is specially designed for erosion control applications on steep slopes and vegetated waterways. The matrix is composed of polypropylene monofilament yarns featuring X3® technology woven into a uniform configuration of resilient pyramid-like projections. The material exhibits very high interlock and reinforcement capacity with both soil and root systems, demonstrates superior UV resistance, and enhances seedling emergence.

PYRAMAT® conforms to the property values listed below[1] and is manufactured at a Propex facility having achieved ISO 9001:2000 certification. Propex performs internal Manufacturing Quality Control (MQC) tests that have been accredited by the Geosynthetic Accreditation Institute – Laboratory Accreditation Program (GAI-LAP).

PROPERTY	TEST METHOD	ENGLISH	METRIC
ORIGIN OF MATERIALS			
% U.S. Manufactured Inputs		100%	100%
% U.S. Manufactured		100%	100%
PHYSICAL			
Mass/Unit Area [2]	ASTM D-6566	13.5 oz/yd²	458 g/m²
Thickness [2]	ASTM D-6525	0.40 in	10.2 mm
Light Penetration (% Passing) [3]	ASTM D-6567	10%	10%
Color	Visual	Green or Tan	
MECHANICAL			
Tensile Strength [2]	ASTM D-6818	4000 x 3000 lbs/ft	58.4 x 43.8 kN/m
Elongation [2]	ASTM D-6818	40%	40%
Resiliency [2]	ASTM D-6524	80%	80%
Flexibility [4]	ASTM D-6575	0.534 in-lb	616,154 mg-cm
ENDURANCE			
UV Resistance % Retained at 6,000 hrs [4]	ASTM D-4355	90%	90%
UV Resistance % Retained at 10,000 hrs [4]	ASTM D-4355	85%	85%
PERFORMANCE			
Velocity (Vegetated) [4, 5]	Large Scale	25 ft/sec	7.6 m/sec
Shear Stress (Vegetated) [4, 5]	Large Scale	16 lb/ft²	766 Pa
Manning's n (Unvegetated) [4, 6]	Calculated	0.028	0.028
Seedling Emergence [4]	ASTM D-7322	296%	296%
ROLL SIZES		8.5 ft x 90 ft 15.0 ft x MR	2.6 m x 27.4 m 4.6 m x MR

NOTES:

1. The property values listed above are effective 07/13/2015 and are subject to change without notice.
2. Minimum average roll values (MARV) are calculated as the typical minus two standard deviations. Statistically, it yields a 97.7% degree of confidence that any samples taken from quality assurance testing will exceed the value reported.
3. Maximum Average Roll Value (MaxARV), calculated as the typical plus two standard deviations. Statistically, it yields a 97.7% degree of confidence that any sample taken during quality assurance testing will meet to the value reported.
4. Typical Value.
5. Maximum permissible velocity and shear stress has been obtained through vegetated testing programs featuring specific soil types, vegetation classes, flow conditions, and failure criteria. These conditions may not be relevant to every project nor are they replicated by other manufacturers. Please contact Propex for further information.
6. Calculated as typical values from large-scale flexible channel lining test programs with a flow depth of 6 to 12 inches.

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Figure 40 Pyramat PDS

IECA Member

ECTC Directing Member

Specifications

Western Excelsior manufactures a full line of Rolled Erosion Control Products (RECPs). Excel PP5-10 Turf Reinforcement Mat is composed of 100% synthetic components. A matrix of green polypropylene fibers is mechanically (stitch) bound between two UV stabilized, heavy duty synthetic nets. Stitching is secured on two inch centers using UV stabilized, heavy duty polypropylene thread. Excel PP5-10 is a permanent, three-dimensional TRM that provides immediate erosion protection and long term turf reinforcement and is intended for slope or channel applications requiring erosion protection for greater than thirty-six months.

Each roll of EXCEL PP5-10 is made in the USA and manufactured under Western Excelsior's Quality Assurance Program to ensure a continuous distribution of fibers and consistent thickness. Typical manufactured properites are provided in Table 1 and product characteristics are provided in Table 2.

Table 1- Specified Expected Values

Tested Property	Test Method	Value
Tensile Strength (MD) x (TD)	ASTM D6818	20.8 lb/in (3.6 kN/m) x 17.7 lb/in (3.1 kN/m)
Elongation (MD) x (TD)	ASTM D6818	25 % x 25 %
Mass Per Unit Area	ASTM D6566	10.0 oz/yd^2 (339 g/m^2)
Thickness	ASTM D6525	0.36 in (9 mm)
Light Penetration	ASTM D6567	25 % open
Water Absorption	ASTM D1117	N/A %
Resiliency	ASTM D 6524	87 %
Porosity	Computed	96 %
UV Stability	ASTM D 4355	100% (500hr) / 90% (1000hr) %

Table 2 - Netting

Top Net Type	Synthetic, UV Stable
Bottom Net Type	Synthetic, UV Stable
Top Net Opening Dimensions	0.7 in (17 mm) x 0.7 in (17 mm)
Bottom Net Opening Dimensions	0.7 in (17 mm) x 0.7 in (17 mm)

Excel PP5-10 is available in multiple roll sizes ranging in width from 8.0 ft to 16.0 ft. and 112.5 ft to 600 ft in length. Standard roll sizes are 100 square yards, measuring 8.0 ft wide by 112.5 ft long. Custom roll sizes are available upon request.

Document # WE_EXCEL_PP510_SPEC. This document has been developed to provide the characteristic properties of the product described. For questions, to request performance data or installation recommendations, contact Western Excelsior at 866-540-9810 or wexcotech@westernexcelsior.com. Updated 4/14/2014.

Figure 41 Excel PP5-10 PDS

Specifications

Western Excelsior manufactures a full line of Rolled Erosion Control Products (RECPs). PP5-Heavy Duty™ is a fully synthetic, UV stable Turf Reinforcement Mat (TRM) manufactured by weaving continuous, synthetic thread elements by way of a proprietary (patent pending) process to form a lofty, three-dimensional pattern. PP5-Heavy Duty is resistant to environmental and climatic conditions and provides high strength, durability and turf reinforcement performance.

Each roll of PP5-Heavy Duty is made in the USA and manufactured under Western Excelsior's Quality Assurance Program to ensure a consistent distribution of strands and consistent thickness. PP5-Heavy Duty is constructed of UV stabilized, high strength synthetic yarns to be incorporated into turf and/or the soil matrix. For typical applications, the expected design life of PP5-Heavy Duty is twenty-five years, however, may be less or indefinite. Typical manufactured properites are provided in Table 1 and product characteristics are provided in Table 2.

Table 1- Specified Expected Values

Tested Property	Test Method	Value
Tensile Strength (MD) x (TD)*	ASTM D6818	2500 lb/ft (36 kN/m) x 2250 lb/ft (33 kN/m)
Elongation (MD) x (TD)	ASTM D6818	25 % x 20 %
Tensile Strength @15% Strain	ASTM D6818	2250 lb/ft (44 kN/m) - (MD &TD)
Initial Tangent Modulus (MD)	ASTM D6818	8.0 kip/ft (9.7 kN/m)
Initial Tangent Modulus (TD)	ASTM D6818	13.0 kip/ft (15.8 kN/m)
Mass Per Unit Area	ASTM D6566	9.2 oz/yd^2 (312 g/m^2)
Thickness	ASTM D6525	0.30 in (8 mm)
Light Penetration	ASTM D6567	30 % open
Water Absorption	ASTM D1117	N/A %
Resiliency	ASTM D 6524	70 %
Porosity	Computed	96 %
UV Stability	ASTM D 4355	100% (500hr) / 90% (3000hr)

*Value specified as Minimum Average Roll Value (MARV)

Table 2 - Netting

PP5-Heavy Duty is a woven product, thus no netting is utilized in the construction of the material.

PP5-Heavy Duty is available in multiple roll sizes ranging in width from 8.0 ft to 12.0 ft. and 112.5 ft to 180 ft in length. Standard roll sizes are 100 square yards, measuring 8.0 ft wide by 112.5 ft long. Custom roll sizes are available upon request. Large rolls may require a cardboard core. PP5-Heavy Duty is manufactured in the USA with 100% of component materials derived from domestic sources.

Document # WE_EXCEL_PP5HD_SPEC. This document has been developed to provide the characteristic properties of the product described. For questions, to request performance data or installation recommendations, contact Western Excelsior at 866-540-9810 or wexcotech@westernexcelsior.com. Updated 4/14/2014.

Figure 42 PP5-Heavy Duty PDS

Specifications

Western Excelsior manufactures a full line of Rolled Erosion Control Products (RECPs). PP5-Xtreme™ is a fully synthetic, UV stable High Performance Turf Reinforcement Mat (HP-TRM) manufactured by weaving continuous, synthetic thread elements by way of a proprietary (patent pending) process to form a lofty, three-dimensional pattern. PP5-Xtreme is resistant to environmental and climatic conditions and provides high strength, durability and turf reinforcement performance.

Each roll of PP5-Xtreme is made in the USA and manufactured under Western Excelsior's Quality Assurance Program to ensure a consistent distribution of strands and consistent thickness. PP5-Xtreme is constructed of UV stabilized, high strength synthetic yarns to be incorporated into turf and/or the soil matrix. For typical applications, the expected design life of PP5-Xtreme is fifty years, however, may be less or indefinite. Typical manufactured properites are provided in Table 1 and product characteristics are provided in Table 2.

Table 1- Specified Expected Values

Tested Property	Test Method	Value
Tensile Strength (MD) x (TD)*	ASTM D6818	4000 lb/ft (58 kN/m) x 3000 lb/ft (44 kN/m)
Elongation (MD) x (TD)**	ASTM D6818	25 % x 20 %
Tensile Strength @15% Strain	ASTM D6818	3000 lb/ft (44 kN/m) - (MD &TD)
Initial Tangent Modulus (MD)	ASTM D6818	10.5 kip/ft (12.8 kN/m)
Initial Tangent Modulus (TD)	ASTM D6818	17.5 kip/ft (21.3 kN/m)
Mass Per Unit Area	ASTM D6566	9.2 oz/yd^2 (312 g/m^2)
Thickness	ASTM D6525	0.30 in (8 mm)
Light Penetration	ASTM D6567	30 % open
Water Absorption	ASTM D1117	N/A %
Resiliency	ASTM D 6524	70 %
Porosity	Computed	96 %
UV Stability	ASTM D 4355	100% (500hr) / 90% (6000hr)

*Value specified as Minimum Average Roll Value (MARV) **Maximum

Table 2 - Netting

PP5-Xtreme is a woven product, thus no netting is utilized in the construction of the material.

PP5-Xtreme is available in multiple roll sizes ranging in width from 8.0 ft to 12.0 ft. and 112.5 ft to 180 ft in length. Standard roll sizes are 100 square yards, measuring 8.0 ft wide by 112.5 ft long. Custom roll sizes are available upon request. Large rolls may require a cardboard core. PP5-Xtreme is manufactured in the USA with 100% of component materials derived from domestic sources.

Document # WE_EXCEL_PP5XT_SPEC. This document has been developed to provide the characteristic properties of the product described. For questions, to request performance data or installation recommendations, contact Western Excelsior at 866-540-9810 or wexcotech@westernexcelsior.com. Updated 4/14/2014.

Figure 43 PP5-Xtreme PDS

APPENDIX B

FIELD EVALUATION TEST DATA

Product	Pyramat		
Installation Date	Jun 2002		
Sample Date	May 2015		
Time of Exposure	13 yrs		

Sample #	Tensile Strength MD		Elongation
	lb/in	lb/ft	
1	410.50	4,926.0	42%
1	381.00	4,572.0	43%
1	355.25	4,263.0	35%
1	418.25	5,019.0	40%
1	360.75	4,329.0	32%
2	325.75	3,909.0	30%
2	317.25	3,807.0	36%
2	369.50	4,434.0	41%
2	437.50	5,250.0	43%
2	393.00	4,716.0	40%
3	357.25	4,287.0	26%
3	346.50	4,158.0	28%
3	330.75	3,969.0	27%
3	326.75	3,921.0	25%
3	363.75	4,365.0	28%
4	348.25	4,179.0	29%
4	248.85	2,986.2	20%
4	281.25	3,375.0	23%
4	266.75	3,201.0	23%
4	370.25	4,443.0	32%
5	347.75	4,173.0	39%
5	368.25	4,419.0	39%
5	366.25	4,395.0	37%
5	404.25	4,851.0	41%
5	411.25	4,935.0	41%
Average	356.27	4,275.3	34%
Std Dev	45.98	551.8	7%
MARV	264.31	3,171.7	19%

	Percent Retained	79.3%	
	Equation of Curve	$y = e^{-0.009x}$	
	y	79.3%	AV
	x	25.8	6.0

Figure 44 Pyramat Test Data

Product	PP5-Xtreme		
Installation Date	May 2013		
Sample Date	Nov 2014		
Time of Exposure	1.5 yrs		

Sample #	Tensile Strength MD		Elongation
	lb/in	lb/ft	
1	264.25	3,171.0	18%
1	244.70	2,936.4	24%
1	233.25	2,799.0	19%
1	273.75	3,285.0	25%
1	246.18	2,954.2	23%
Average	252.43	3,029.1	22%
Std Dev	16.29	195.4	3%
MARV	219.85	2,638.2	16%

Percent Retained	66.0%	
Equation of Curve	$y = e^{-0.013x}$	
y	66.0%	**AV**
x	32.0	0.6

Figure 45 PP5-Xtreme Test Data

VITA

Drew Loizeaux was born in Spokane, WA, to the parents of Marc and Anita Loizeaux. He is the fourth of four children, an older sister and two older brothers. He was homeschooled for elementary school and attended Silverdale Baptist Academy for High School in Chattanooga, Tennessee. After graduation, he attended the University of Tennessee at Chattanooga where he completed the Bachelors of Science degree in in May 2011 in Civil Engineering. He married his high school sweetheart in the same month and they have three beautiful children; Ryan, Violet and Eloise. Drew worked full time as an applications engineer for a geosynthetic manufacturing company and continued graduate school at the University of Tennessee at Chattanooga in the Civil Engineering Program. Drew graduated with a Master's of Science degree in Engineering in December 2015.